THE EFFECT OF SEAT TYPE ON STROKE KINEMATICS AND TRUNK ROTATOR ACTIVITY DURING KAYAK ERGOMETER PADDLING

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Abstract

Kayakers have traditionally used a fixed seat but in 2005 a “swivel seat”, able to rotate in the horizontal plane, was approved for use in races. While anecdotal evidence has suggested that the swivel seat may improve performance, the available data are limited and mainly physiological. The aim of this study was to investigate the effect of the swivel seat on kinematics and trunk muscle activation during paddling on ergometer.

Nine experienced kayakers volunteered for this study and each completed two maximal trials of 30 s on the ergometer, one with the swivel seat and the other with a fixed seat. Three-dimensional motion analysis and performance data were collected at 200Hz during the central 10 s of each trial. Surface electromyographic (EMG) signals were recorded at 2000Hz bilaterally from the rectus abdominis, external oblique, internal oblique, latissimus dorsi and the erector spinae muscles.

The use of the swivel seat was observed to improve performance through a significant increase in peak flywheel RPM ($p = 0.033$), right paddle recovery time ($p = 0.043$) and paddle antero-posterior displacement ($p = 0.015$). Shoulder rotation increased when using the swivel seat but trunk rotation decreased significantly ($p = 0.019$). In addition, EMG analysis suggested greater activation of the trunk muscles during the swivel seat condition, where body position was closer to the recommended upright orientation and the knee range of motion was increased ($p < 0.01$).

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1. Introduction

The aim of flatwater kayaking is to cover a specific distance as fast as possible, crossing the finish line before your opponents (Begon et al., 2010). The paddling action is defined by cyclic movements performed by the upper limbs coordinated with pedalling movements of the lower limbs and trunk rotation (Plagenhoef, 1979; Logan and Holt, 1985). In addition to the requirement for great levels of physiological capacity, the performance of an elite kayaker is influenced by a complex combination of determinants involving the kinematics of the boat, paddle and paddler and the forces acting on all three (Robinson et al., 2002).

Biomechanists have traditionally used cinematography to track athletes' performance with 2D (two-dimensional) methodology employed to determine kinematic parameters on-water and on-ergometer (Plagenhoef, 1979; Campagna et al., 1982). However, a complete picture of the stroke could not be obtained until the introduction of 3D (three-dimensional) analysis (Kendal and Sanders, 1992; Ong et al., 2006).

Physiology has traditionally dominated research in flat water kayaking, however, the importance of kinematics in performance has attracted the attention of researchers (Robinson et al., 2002). As for kinetics, investigation of drag and lift forces has provided valuable information concerning their relationship with boat movement (Jackson et al., 1992). To guarantee optimal performances minimising drag forces acting on the hull and maximising propulsion become essential. As far as regulations have permitted it, most of the traditional advancements in boat shape and blade design have focused on these factors to lead to the largest improvements in performance (Kendal and Sanders, 1992; Robinson et al., 2002). Recently, the influence of the seat and footplate has sparked investigation concerning setting-up and the forces applied by the kayaker (Ong et al., 2006; Petrone et al., 2006; Michael et al., 2009). However, no clear conclusions have been drawn in these areas. One particularly notable development was the introduction in 2005 of a new seat design – "the swivel seat" – that rotates about its vertical axis, facilitating the kayaker's trunk movement. This revolutionary piece of equipment has not been widely studied with the kinematic effects of this seat on performance having not been analysed in great detail. The only study to date on the effects of the rotational seat on performance has been from a physiology perspective (Michael et al., 2010). When compared with the traditional seat no changes in oxygen consumption were detected whereas the power output was significantly higher with the rotational seat. As similar values were obtained for physiological parameters (VO_2, HR peak and lactate production) it was suggested that these improvements in performance might have come from kinematics (Michael et al., 2010).

Further research is needed to determine the effects of different seat designs on the kinematics, muscle activation and kinetics of kayaking. Due to the practical difficulties associated with data collection during on-water paddling, ergometer-based investigations are a logical starting point. Once the effects of the swivel seat have been determined in detail during ergometer paddling, subsequent on-water research can be attempted in order to confirm the findings of prior studies and identify the consequences of the swivel seat use on technique and on kayak movement under real conditions. Therefore, the aim of the present study was to analyse the kinematics and the trunk muscle activation comparing the use of two different seats, the swivel and the traditional fixed seat, while paddling on an ergometer.

2. Literature Review

Kayaking is a cyclic sport composed of the combined actions of trunk, upper and lower limb muscles throughout a coordinated motion with alternating left and right strokes (Begon et al., 2010). Flatwater kayaking, the oldest discipline, has been an Olympic event since the 1936 Berlin Games. The final criterion which determines kayak performance is the time required by the paddlers to cover the only three Olympic distances of 200, 500, 1000 meters (Begon et al., 2008a; Michael et al., 2009; ICF, 2011). To avoid direct contact between kayakers, nine different lanes are used in which the boats, individually, cover the distance at the same time without interacting with others (Alacid et al., 2010a).

Optimal performance in kayaking is the result of a combination of anthropometric, physiological, biomechanical and psychological aspects which may be studied through scientific procedures (Mann and Kearney, 1980; Fry and Morton, 1991; van Someren et al., 2000; Ackland et al., 2003; Michael et al., 2010). The identification of relevant procedures, and the associated levels of the measured attributes, are essential for obtaining a successful performance (Bishop, 2000).

Traditionally, research in kayaking has primarily focused on physiological testing of the athletes to determine fitness levels and to then tailor training programs to optimize physiological fitness (Aitken and Neal, 1992). Early studies analysed VO_{2max} to monitor and assess the physiological capacity of elite kayakers (Tesch et al., 1976; Pendergast et al., 1979). Comparisons between elite and amateur flatwater paddlers identified greater peak rates of oxygen consumption in elite kayakers and significant differences between both groups in terms of anthropometric parameters (Fry and Morton, 1991; van Someren et al., 1999). Nevertheless, the measurement of the maximal oxygen consumption of paddlers was not the only possible determinant of performance investigated by physiologists. While race characteristics demand that kayakers paddle most of the race at or around peak VO_2 (Bishop, 2000), requiring a high aerobic power, the anaerobic contribution is also quite important for successful performance and it should not be overlooked (Michael et al., 2008). The demands of the anaerobic and the aerobic systems have been studied under many conditions:

after performing different warm-ups (Bishop et al., 2001; Bishop et al., 2003), on ergometers (Tesch, 1983; van Someren et al., 2000; van Someren and Oliver, 2002) and at different pace strategies (Bishop et al., 2002).

However in the past few years sports engineering and biomechanics have become as important to athletic performance as physical and psychological conditioning (Robinson et al., 2002). It is commonly believed that the analysis of kinematics in on-water sports such as kayaking or rowing developed from the procedures used in early studies in swimming (East, 1970; Craig and Pendergast, 1979). As a means of evaluating swimming technique, the velocity of swimmers was examined as the product of stroke rate and stroke length (Alacid et al., 2008a). In contrast to those studies in swimming which found that stroke length was the most determinant factor in obtaining high average velocities (Craig and Pendergast, 1979; Craig et al., 1985), most studies in kayaking performance have highlighted the stroke rate as the most important determinant (Mann and Kearney, 1980; Kendal and Sanders, 1992; Sanders and Baker, 1998). In terms of forces, the combination of two determinants defines the average velocity of the boat: the propulsive effort produced by the kayaker and the drag forces acting on the boat (Baudouin and Hawkins, 2002). By integrating the practical knowledge of the kinetics (forces acting on the craft and the paddler) with the study of kinematics (motion of the craft and paddler), kayak paddling performance would be enhanced through a better and more complete understanding of the effects determining boat velocity (Robinson et al., 2002).

Although technique in flatwater kayaking has usually been analysed on water (Plagenhoef, 1979; Logan and Holt, 1985) and over Olympic distances (Issurin, 1998), the number of kinematic studies undertaken indoors relating to kinematics has increased significantly due to the recent improvements in how accurately kayak ergometers simulate on-water conditions (Begon et al., 2009; Michael et al., 2012).

2.1. On-water analysis

The first on-water studies in kayak kinematics were carried out by tracking the athletes, using a single camera to provide a two-dimensional analysis (Plagenhoef, 1979; Mann and Kearney, 1980). The camera was usually positioned to one side in order to record a short straight space which the kayakers passed through. Subsequent manual digitisation of the performance of athletes was needed in order to provide appropriate data for analysis. Plagenhoef (1979) undertook an investigation to identify the determinants of performance by analysing the differences between the most and least successful flatwater kayakers. A subsequent study has investigated in greater detail the basic biomechanical parameters of Olympic flatwater paddlers and the bilateral asymmetries of the stroke in two-dimensions, focusing on the displacements and velocities of joint centres in the upper limbs and the relationship between the pattern of kayak movement and the movement of body segments (Mann and Kearney, 1980).

However, a complete analysis of the paddling phases was not undertaken until 1985 when Logan and Holt reported a detailed analysis of the muscles and segments involved in each part of the kayak cycle. To facilitate this analysis from a paddle perspective, the cycle was divided into four phases based on the motion of one of the paddle's blades: (1) the catch, starting with the paddle horizontal and the blade forward and ending when the same side blade is completely submerged in the water; (2) the pull, starting with the blade buried in the water and ending when its removal from the water is initiated; (3) the exit, starting with the blade in the submerged position and ending when the paddle reaches the horizontal position in the air; and (4) the recovery, during which the selected blade is moved forward through the air from the backward horizontal paddle position to the forward horizontal forward position (Logan and Holt, 1985).

The combined effect of the increasing role of sports biomechanics and the technological explosion associated with image processing and automated digitisation opened the doors to many more projects (Shapiro and Kearney, 1986). The use of two cameras, one camera with the lens axis perpendicular to the plane of motion (lateral) and another with the lens axis in the intended plane of motion of the kayak (frontal), was proposed by Kendal and Sanders (1992). A more complete picture of the movement pattern, including the paths of the paddle and the body segments, was obtained from the information provided by the lateral camera and the complementary data acquired from the frontal view.

In one of the first studies using a 3D system, Baker et al. (1999) digitised video footage of eight anatomical landmarks, two paddle markers, and two boat markers using the APAS digitizing system and reconstructed the 3D kinematics. However, no general conclusions could be drawn regarding the paddlers' technique because their study was apparently an initial investigation limited in terms of participants to comparing technique between males and females (Baker et al., 1999, cited by Michael et al., 2009). Further 3D analysis was undertaken by Ong (2006) who investigated the effect of different boat set-ups on kinematics. By using a six-camera system the position of 10 non-collinear markers were derived prior to testing. Two synchronized NAC video cameras (50 Hz) positioned at 90° to each other, recorded the performance of three elite kayakers at maximum speed through a calibrated space (6 m x 1.2 m x 2 m) on a calm bay. The use of a larger number of cameras in 3D analysis facilitates the creation of full-body models and accurate estimation of the movement patterns through markers which may be placed directly on anatomical landmarks and that, otherwise, might be obscured if only one or two cameras were used. In combination with force data, 3D kinematic analysis has become a powerful instrument for estimating complex force moments and integrating the kinetics and kinematics from multiple planes (Michael et al., 2009, 2012)

Despite the limitations of 2D analysis, it is still a useful tool for coaches and researchers to utilise in analysing kinematic parameters due to its relative ease of use and the more manageable amount of data that are generated. From such analysis valuable information concerning performance such as paddle entry and exit angles, stroke length, stroke rate, and in-water times can be determined (Sperlich and Baker, 2002). Thus, in the recent years, some analyses of the changes in kinematics over long distances have been conducted in 2D from a vehicle moving perpendicularly alongside the crafts (Alacid et al., 2008b; Ho et al., 2009; Alacid et al., 2010b). The possibility of having a sagittal view of the kayaker during the whole performance allows the capture of a cycle (one side blade entry to same side blade entry). Kinematics, especially boat velocity, stroke frequency and stroke length, can be easily calculated by taking as a reference the buoys of the lanes which indicate the distance. However, whilst these techniques have permitted enhanced 2D analysis, it is questionable whether they provide a complete and sufficiently detailed picture of the whole stroke technique, which is very 3D in nature.

2.2. On-ergometer analysis

Most sports practised outdoors are usually dependent on weather conditions and athletes on occasion are unable to carry out their training programme under real conditions. Traditionally, in kayaking, in an attempt not to miss out on periods of training, paddlers were recommended to practise other physical activity such as cross-country skiing or swimming in order to improve or maintain their level of fitness. However, the muscles involved in those activities are not the same as the muscles used in flatwater kayaking (Campagna, 1986). To overcome this disadvantage, scientists tried to develop systems to focus more on conditioning the upper body muscles properly and to assess a kayaker's performance. Pike et al. (1973, cited by Stothart, 1986a), modified a Monark bicycle ergometer to create ergometers for both canoeing and kayaking. Campagna (1982) developed an ergometer which attempted to reproduce on-water conditions more accurately by adapting a Biokinetic Swim Bench. Subsequent studies continued to introduce modifications in the ergometers to improve their similarities to on-water kayaking conditions and, therefore, provide athletes with a more appropriate method for training out of the water (Telford, 1982; Campagna, 1986; Stothart et al., 1986a; Witkowski et al., 1989). Larson (1988) developed a new kayak ergometer based on air resistance which consisted of a separate seat and a multi-purpose ergometer mounted on a braked flywheel. The flywheel, whose function was to simulate the water drag force on the paddle blade, was automatically rewound by two elastic wires placed in the rear of the ergometer. Although prior studies had already obtained digital data from an ergometer (Stothart et al., 1986a), the use of the flywheel allowed the acquisition of more detailed information about power output, maximum speed, distance and performance time.

Conventional kayaking ergometers have been designed with a static seat and footrest (Begon et al., 2008a). Therefore, the loss of propulsive force transmitted to the paddler's body is minimal (Elliott et al., 2002) as the paddler can push against a static footrest. However, in a real boat the seat-footrest system moves more than the blade (Elliott et al., 2002). Conscious of this problem, Begon et al., (2008a) designed a kayak ergometer based on a slide trolley which reproduced on-water dynamics more accurately. The trolley included the seat and the footrest and it was able to slide forward and backward along a static frame.

From a research point of view, the natural environment where flatwater kayaking is practised can make in-situ data collection difficult. Therefore, ergometers have become useful tools through which additional information could be obtained. Although kayak ergometers were originally designed for training under unfavourable outdoor conditions (Begon et al., 2009), they can offer two extra functions for the sport scientist. Firstly, they can be used to assess the physical working capacity of athletes by setting up an externally-specified stroke frequency, working time and power output. Secondly, they may function as tools for investigating the nature of kayak stroke technique and kinematics in general (Stothart et al., 1986a). In addition, the possibility of carrying out the studies indoor, without the movement of the boat, combined with the provision of immediate feedback allows a more effective approach as both kinematic and physiological measurements are performed.

One of the most valuable parameters which can be obtained through the use of an ergometer is the power output generated when paddling. Sanderson and Martindale (1986) identified the determinants of the propulsive power in rowing as stroke length (SL), stroke rate (SR) and force applied on a rowing oar. Telford (1982) compared the maximal power outputs provided by ergometers in different sports. Maximum power outputs were obtained over 10- and 20-s trials, with the finding that the kayak ergometer produced the lowest values (352±50 W) while leg/arm cycling (985±162 W) generated the largest. The power output required to maintain the boat velocity is assumed to be proportional to the cube of that velocity (Michael et al., 2010). Another approach to determining the relationship between velocity and power was carried out by Campagna et al. (1998). A regression equation to predict performance was obtained from two similar tests performed on-ergometer and on-water. Nevertheless, these equations are slightly inexact because other factors which may influence the velocity, such as water viscosity, were not taken into consideration.

Resultant paddle and body kinematic parameters on an ergometer have not been studied yet in great detail. In an attempt to analyse the kinematics of the upper limbs, Kranzl et al. (1996) undertook the first study on a kayak ergometer using a 3D multi-camera system. The forward stroke of ten elite whitewater kayakers was analysed using 21 passive markers and a 6-camera motion capture system usually employed in the analysis of clinical gait (Kollmitzer, 1994). Using a modified swimming bench as a kayak ergometer, Wassinger et al. (2011) analysed the 3D scapulo-humeral motion in whitewater kayakers. Segment position and orientation were determined using electromagnetic tracking for the first time in kayaking. Further research with flatwater kayakers has used more traditional tracking systems with infrared cameras (Petrone et al., 2006) and digital video cameras (López and Ribas, 2011). Traditionally, kinematic and kinetic variables in kayaking have been investigated separately, with few relationships between the two being found in the literature. A recent investigation by Michael et al. (2012) has, however, attempted to consider both areas by simultaneously collecting paddle force and paddle angle data on an ergometer.

Despite the efforts of biomechanists and engineers in improving the quality of ergometers in terms of how closely they reproduce the on-water conditions, the validity of the kinematic results obtained from on-ergometer investigations has been called into question (Begon et al., 2008a; Michael et al., 2012). Several studies have supported the use of ergometers as an effective representation of the kinematics and physiological demands of kayaking (Michael et al., 2010; Fleming et al., 2012). The exact correspondence between on-ergometer and on-water kinematics parameters remains unknown, however, and future research in this area will be warranted as on-water data collection techniques advance.

Regarding the relative physiological demands between on-water and on-ergometer kayaking, Barnes and Adams (1998) compared the physiological responses during a 120-sec on-ergometer test with those during a 500-m maximal intensity water-based kayak paddle. In this case the physiological responses obtained indoors were not representative of those observed in the on-water sprint. Differences in response were also obtained by Alacid et al. (2006b), when 20-s tests were performed under both conditions. However, other studies that have investigated similar parameters over different distances and with more participants have reported similar responses when related tests are performed under on-water and on-ergometer conditions (Larsson et al., 1988; Cuesta et al., 1991; van Someren and Dumbar, 1997; van Someren et al., 2000).

2.3 Muscle activation

In terms of muscle activation little research has been conducted. Fleming et al. (2007, 2012) reported greater peak activity in the deltoids and triceps when paddling indoors and on-water respectively, attributing these results to the nature of the ergometer's loading mechanism. In contrast to findings reported by Trevithick et al. (2007), shoulder muscle recruitment during the recovery phase increases to maintain shoulder position as a downward force is generated by ergometer recoil (Fleming et al., 2012). As previously reported in other sports involving upper body pulling motions such as swimming (Pink et al., 1991) the latissimus dorsi increases its activity during the pull phase, becoming the primary muscle of propulsion (Trevithick et al., 2007). Although no other significant differences in peak muscle activation between conditions have been identified, an earlier activation has been identified in the latissimus dorsi when paddling on an ergometer (Fleming et al., 2012). Moreover, Brown et al. (2010) studied the bilateral differences of trunk and leg muscle activation, reporting the great importance of the abdominals during the entire paddling cycle.

2.4 Differences in kinematics

As for the differences between indoor and on-water paddling in terms of kinematics, contradictory results have been obtained. Campagna (1982, 1986), in two of the first kinematic studies involving an ergometer, found similar trajectories for the elbow and wrist. Supporting the similarity of the movement under the two conditions, Witkowski et al (1989) noted that very similar forces were measured by tensometric and rotation transducers. In rowing, similar studies comparing the equivalent conditions corroborated the similarity in leg and trunk kinematics (Lamb, 1989). However, subsequent studies that used more advanced technology to analyse differences in technique, found contradictory results. In a comparison of the upper joint paths between the conditions, Begon et al. (2008b) reported high correlation in all joints except for the shoulder. In addition, Begon et al. (2003, 2008b) found no differences in stroke phase times when ergometer paddling was compared with in-situ performance. Conversely, the same studies reported significant differences when their ergometer values were contrasted with on-water values from prior studies. In kayaking it is known that the stroke frequency is one of the most influential factors determining paddlers' performance (Mann and Kearney, 1980; Sanders and Baker, 1998). Barnes and Adams (1998) compared stroke frequencies between a 120-s maximal ergometer trial and a 500-m on-water trial, reporting significantly higher values indoors. Similar results were obtained by some later investigations, corroborating the difference in stroke rate (Alacid et al., 2006a; Alacid et al., 2006b). Recent studies have revealed contradictory results as Carrasco (2010) obtained high correlation between stroke rates on-ergometer and on-water. To date biomechanical studies have demonstrated quite similar parameters between the two conditions and stroke frequency has been the only variable showing significant differences in the majority of the investigations. However, more research about technique, joint paths and range of motions is needed in order to analyse how the technique changes under both conditions because little research have been undertaken until now (Begon et al., 2003; Fleming et al., 2012). The situation is complicated further due to the wide range of ergometer designs available. In rowing, comparisons between ergometers with different mechanisms have reported significant differences not only in physiological variables but also in terms of stroke parameters and power outputs (Colloud et al., 2006; Benson et al., 2011). However while the different characteristics of each ergometer mean that the paddling kinematics cannot be assumed to be identical on each, no evidence to date suggests that ergometer paddling is fundamentally different from on-water paddling, and ergometers have become an effective tool for investigating kayak kinematics and physiology.

2.5 Equipment

Sprint canoeing and kayaking is a sport in which athletes particularly rely on the latest improvements in equipment to obtain good results in competition. In fact, performance improvements have been directly related to technological advancements rather than to changes in training regimes (Robinson et al., 2002). In the past 30 years, hull shape, paddle and blade design have seen more marked modification than has the athlete’s preparation (Ackland et al., 2003).

2.5.1 Boat

One of the components which has changed the most since the first flatwater Olympic competition in Paris in 1924 has been the boat shape. In a historical look at the top performances in the Olympic K1 1000-m event, Robinson (2002) noticed the greatest improvements in performance as new boat designs were introduced. As an example, Gert Fredriksson, with the introduction of the V-form at the Helsinki Olympic Games, was able to reduce his winning time by more than 25 s. Every new kayak design from the V-form to the most recent models has been focused on reducing the hull surface in contact with the water as well as the boat cross sectional area, in order to decrease the drag force.

There are two types of resistive force - hydrodynamic and aerodynamic drag forces – but kayak movement is predominantly opposed by hydrodynamic drag (Jackson, 1995). There are three hydrodynamic drag forces which act to decelerate the boat velocity: wave drag, pressure drag and friction drag (Pendergast et al., 2005; Michael et al., 2009). Hydrodynamic drag force increases approximately proportionally to the square of the velocity depending on the paddler mass (Hay, 1985; Caplan, 2009). Nevertheless, the most significant contributors to the total drag are friction force and, to a lesser extent, wave drag force. In an attempt to determine relative drag values, Jackson (1995) reported that the speed of the boat was reduced by 0.27% as friction was increased by 1%. It is known than the lower the friction coefficient of the surface in contact with the water, the smaller the friction drag acting over the hull (Jackson, 1995). Friction drag forces can also be reduced by minimizing the wetted surface area. The total weight (paddler and boat) combined with the boat shape are the main factors which determine the wetted surface area of the craft. Body and boat combined weight not only influences the friction drag but also affects the wave drag (Mann and Kearney, 1980; Jackson, 1995; Michael et al., 2009). Additional factors like the cross-sectional area of the hull, also play a key role concerning friction drag forces (Pendergast et al., 2005). This area varies with the oscillations in the net vertical force arising from the buoyancy force and the weight force (Michael et al., 2009). An increase in the cross-sectional area submerged would result in an increase in the drag acting on the kayak. Finally, the kayak length may affect the total boat speed: for a given wetted area, an increase in boat length would lead to an increase in boat speed (Jackson, 1995).

Taking into consideration the different factors which affect the drag force, sports engineers have sought to develop designs and advancements in equipment to minimise these forces, but their efforts have sometimes been limited by the regulations imposed by the International Canoeing Federation (ICF). For example, a new boat design called the “peaked deck” was introduced in 2000 to circumvent the boat beam regulations. In order to comply with the minimum width restrictions, the widest point of the boat was elevated above the waterline allowing the boat to reduce the cross-sectional area submerged. Thus the rule was finally removed some time later as the width beam limitation became worthless (Robinson et al., 2002; Michael et al., 2009) Additionally, restrictions in terms of boat length have also been determined by the ICF (ICF, 2011), thus further investigation of the relationship between length and boat speed has become irrelevant for competition performance purposes.

As was mentioned above, the friction coefficient combined with the hull wetted area are the main determinants of the friction drag. In an investigation of the friction coefficient, Goddard (1996, cited by Robinson et al., 2002), hypothesized that sanded surfaces might reduce the friction by the generation of laminar water flow between the water and the hull. The use of friction-reducing coatings based on hydrophobic molecules has been considered to reduce friction drag as well. However, the ICF has forbidden the use of the texture surfaces as well as the material coatings on the hull for competitions (ICF, 2011). Currently, it seems that the best way to minimise the drag coefficient is to keep the wetted surface of the hull as smooth as possible (Robinson et al., 2002)

Wagner et al. (1993) examined the balance of a rowing boat through the movements generated along its three axes (Figure 1). They were defined as *pitching* (rotation around the mediolateral axis), *rolling* (rotation around the longitudinal axis) and *yawing* (rotation around the vertical axis). Additional movements of the boat which do not change the orientation of the boat’s axes were studied as “translational movements”. *Travelling* was classified as the forward movement, the principal objective of kayaking and rowing. *Sideslipping* was defined as lateral displacements of the boat and *dipping* was identified as the vertical movement (Figure 2). Mann and Kearny (1980) reported the importance of compensating with the body mass the changes in balance generated when paddling. The importance of maintaining the balance of the boat has been related to the amount of drag force generated. The majority of a boat’s movements increase the instantaneous wetted area of the hull leading, in turn, to larger drag forces acting on the boat hull (Baudouin and Hawkins, 2002). Thus the more boat movements the more instantaneous drag forces and the more changes in boat velocity as well. Moreover, optimal performances are associated with the maintenance of the boat velocity and the minimum instantaneous change in body centre of gravity position (Mann and Kearney, 1980; Sanderson and Martindale, 1986). It may be hypothesised that additional boat movements might produce changes in stroke technique as a result of the alteration in body position. Consequently, the propulsion would also be modified and the performance affected.

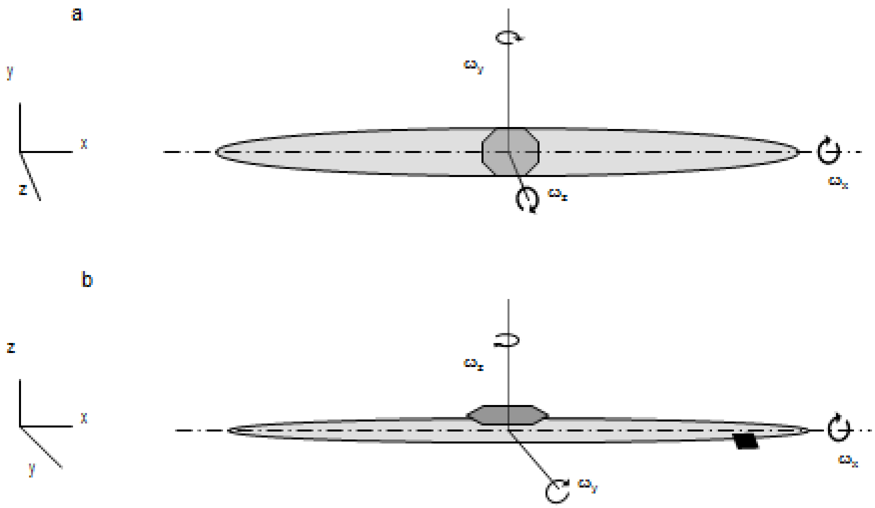

Figure 1 - Plan view (a), and lateral view (b) of the kayak movements around its three axis: rolling (ω_x), pitching (ω_y) and yawing (ω_z).

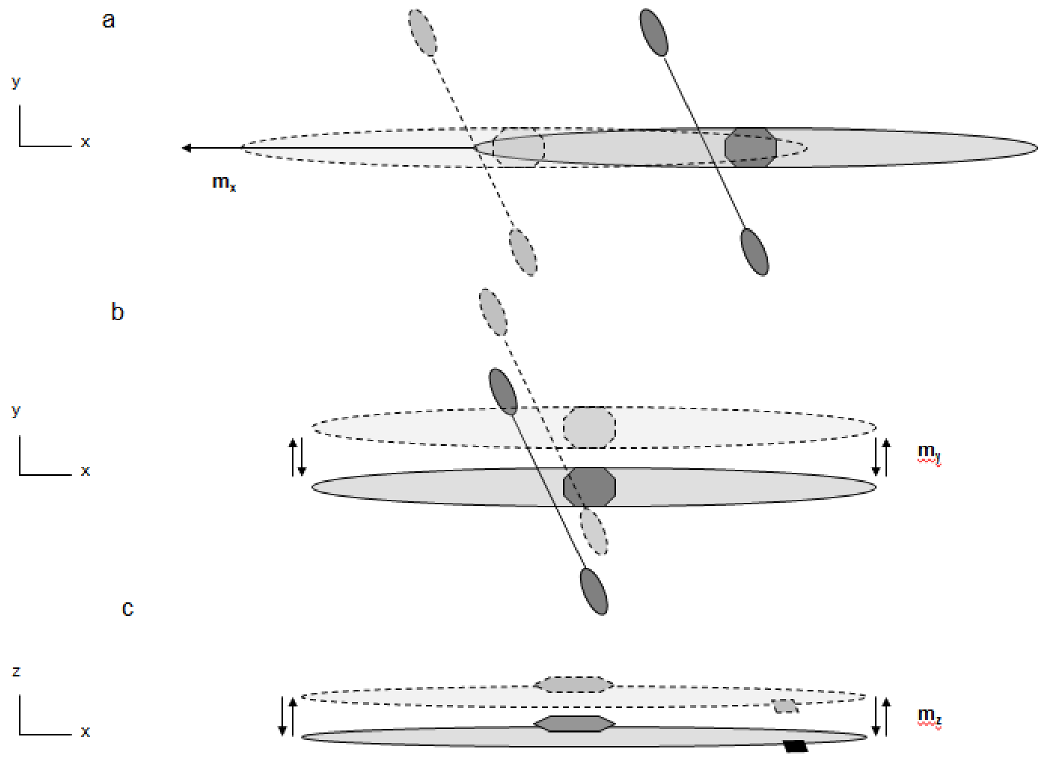

Figure 2 - (a) Plan view of the travelling movement (m_x) of the boat, **(b)** plan view of the sideslipping movement (m_y) of the kayak and **(c)** lateral view of the dipping movement (m_z) of the kayak of the boat .

The minimisation of the factors which affect drag does not, by itself, guarantee good performances. To overcome the complex blend of drag forces which act on the boat it is also paramount to maximize the propulsive factors that contribute to reaching high power outputs (Jackson, 1995; Baudouin and Hawkins, 2002).

2.5.2. Paddle

In kayaking and canoeing the force necessary to propel the craft is provided by the athletes through paddling movements. The forward movement of the boat occurs as the result of the propulsive forces made by the water on the paddle blade during the water phase. This force is transmitted from the paddler to the boat through the seat and the footrest (Ong et al., 2005). The balance between propulsive forces and drag forces determines the distance per stroke and the boat velocity. Due to the discontinuous force transmitted to the water and the dynamic movement of the paddler the boat velocity fluctuates during each stroke (Pendergast et al., 2005;

Michael et al., 2009). There are two components of the net force, which act parallel and normal to the direction of the blade motion. The drag force acts parallel to the relative flow while lift force acts perpendicularly to the direction of the relative flow (Jackson, 1995; Michael et al., 2009). The lack of regulations regarding paddle dimensions and shape has made this element one of the most studied by engineers in the search for better performance.

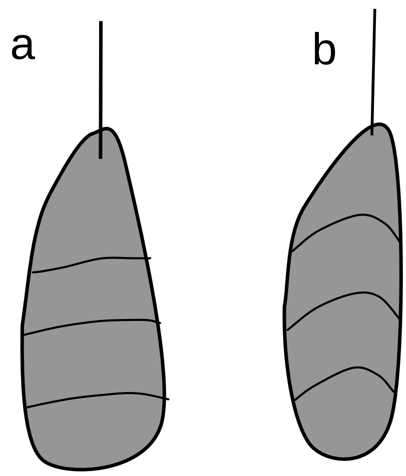

Figure 3 – Wing paddle design (a) and traditional paddle design (b). Adapted from Jackson (1995).

Traditionally, a "flat" paddle model has been used by elite athletes in flatwater kayaking and canoeing. The propulsive forces generated by the blade to propel the boat when a conventional paddle is used are mainly drag forces (Plagenhoef, 1979; Mann and Kearney, 1980). However, in the mid 1980s a new type of paddle based on the airplane wing was designed in Sweden (Figure 3) (Sanders and Baker, 1998). In contrast to the "flat" paddle, the properties of a "wing" paddle involve the use of lift forces, which can only be obtained by changing the paddling technique significantly. To create water flow over the blade, diagonal movements away from the longitudinal axis of the boat are needed (Figure 4; Kendal and Sanders, 1992). The superior performance attained by the wing in comparison with the conventional paddle is based on the greater effectiveness of lift forces in propelling the boat (Jackson et al., 1992; Kendal and Sanders, 1992). It is known that the shape and design of the wing paddle affect the production of lift forces (Sanders and Baker, 1998). However, the drag force acting on the blade is largely independent of the paddle design (Sumner et al., 2003). According to Robinson et al. (2002), Sanders and Kendal (1998) gathered from diverse authors possible explanations for the superiority of the wing paddle which are not contradictory to each other.

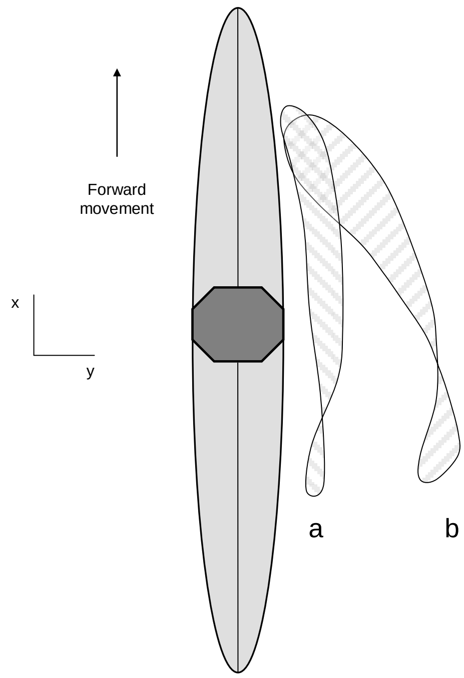

Figure 4 – Plan view of a typical right paddle trajectory when using **(a)** a flat blade design and a **(b)** wing paddle design ("rounding out" technique).

Firstly, when paddling with a traditional blade movements are performed parallel to the longitudinal axis of the boat. This creates some water movements in the direction of motion and part of the energy supplied by the kayaker is "lost" to the water (Sanders and Baker, 1998). With a "rounding out" technique, kayakers perform the paddling movement away from the craft where there is more "still water" (Figure 4).

Related to the previous reason, another advantage of using wing paddles involves braking forces and the stroke time. When paddling parallel to the longitudinal axes of the boat some braking forces are generated. It is necessary to move the blade backwards faster than the boat is moving forward to achieve propulsion forces and avoid braking forces (Sanders and Baker, 1998). The blade must start moving backward before the entry to circumvent braking forces in the first part of the stroke (between the entry and catch). Additionally, the withdrawal of the blade from the water must be produced prior to the completion of the whole pull phase. As a result, the pull time of each stroke is reduced and the recovery time increases to allow the blade entry to start the movement well forward of the kayaker (Sanders and Baker, 1998; Robinson et al., 2002).

Another reason for the superiority of the wing paddle concerns the generation of useful vorticity, which was examined by Jackson et al (1992, 1995) through a mathematical model. The flat paddle would produce a tiny U-shaped vortex while the use of the wing paddle would generate a continuous loop during the movement which might create twice the area of vorticity (Figure 5). The efficiency of the two paddles was estimated to be 89% and 74% for the wing and conventional paddle, respectively (Jackson, 1995). Additionally, the efficiency of a wing paddle increases in comparison with the flat model when using small angles of attack (between 20º-30º) and an angle around 65º to the hull (Jackson et al., 1992).

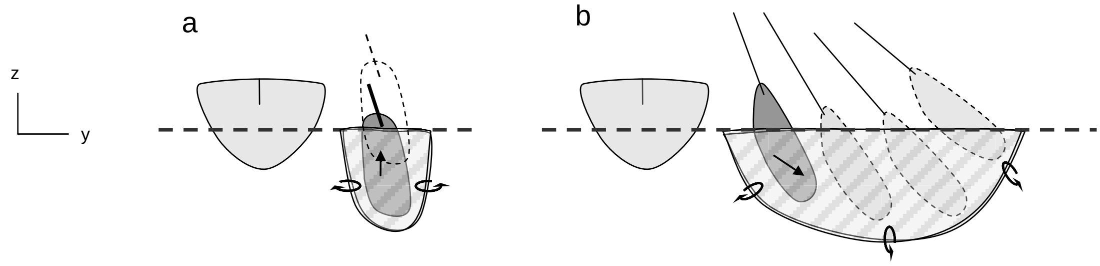

Figure 5 – Sketches of the vortex ring formed at each paddle stroke for **(a)** the traditional blade design and for **(b)** the wing paddle design. Adapted from Jackson (1995).

A fourth possible benefit from the wing paddle is related to the different physiological cost of the two techniques. The “rounding out” stroke technique reduces the energetic cost by allowing the paddler to perform more fluid and natural movements (Sanders and Baker, 1998). Conversely, with the conventional paddle the stroke movements are more intermittent as a result of the sudden reversal of direction at entry and exit blade actions. Consequently the energy cost increases (Jackson et al., 1992; Sanders and Baker, 1998).

The final proposed advantage of the wing paddle relates to the orientation of the blade during the pull phase of the stroke. Moving the paddle away from the boat directs the resultant force more in a forward direction and maintains a vertical orientation of the blade for longer (Sanders and Baker, 1998). Mann (1980) reported that the period when the paddle shaft is vertical is the most effective part of the stroke. Therefore, the more time the blade is pulling perpendicular to the water the more effective are the propulsion and peak horizontal acceleration obtained. For a flat paddle the vertical paddle position seems to occur between 20% and 26% of the stroke from the time of the blade entry to its exit (Plagenhoef, 1979). According to Mann (1980) the vertical position would be reached specifically at 23% of the stroke time. However, when using a wing paddle, the vertical position of the blade does not appear to correspond with the peak propulsion (Aitken and Neal, 1992) cited by Michael (2009). In disagreement with Sanders and Baker (1998), peak propulsion seems to occur slightly before the vertical position is reached (Aitken and Neal, 1992; Fleming et al., 2012)

From the first flat paddles used in the 1936 Berlin Olympic Games to the latest wing model, all the new paddle designs have been developed to enhance elite athlete performances. The improvements in paddle design have been accompanied by meaningful changes in flatwater technique in terms of blade trajectory and body segment paths (Kendal and Sanders, 1992; Sanders and Baker, 1998). However, it seems that the timing of the stroke phases followed by the wing and the flat paddle is quite similar. Although the stroke trajectories followed by these two paddles differ, the timings of the in-water phases seem to follow a similar tendency (Plagenhoef, 1979; Mann and Kearney, 1980; Sanders and Kendal, 1992; Sanders and Baker, 1998).

Direct methods of measuring the force applied to the paddle during single strokes were developed originally in East Germany (Sperlich and Baker, 2002). In an attempt to reliably and accurately evaluate the paddle force production on-water, Stothart et al. (1986b) used a device based on strain gauges placed on the shaft of the paddle. The system was capable of measuring and recording real-time changes in force production during paddling under real conditions. Subsequent studies analysed in further detail the forces generated by the paddlers, through the improvements developed in strain gauges systems (Aitken and Neal, 1992; Baker, 1998). Aitken and Neal (1992) acquired a complete picture of the force production over 500-m trials through analysis of boat velocity and stroke time combined with the main and peak force generated by the athlete. These studies reported peak forces at 36%-45% of the drive time, clearly before the peak velocity point identified by Mann and Kearney (1980) and Kendal and Sanders (1992) as being during the second half of the pull phase, at approximately 70-80% of the drive time. Combining kinematic and kinetic measurements on ergometer, Michael et al. (2012) found a slightly later time for peak paddle forces (43-46% of normalised drive time) than in situ. In a comparison between on-water and on-ergometer kayaking, Fleming et al. (2012) conversely reported a sooner time to peak forces and less force production when paddling on the ergometer. The recoil mechanism and the lack of tension on the ergometer ropes during the first part of the recovery phase are pointed out by the authors as a possible cause of force alterations. Baker et al. (1998) cited by Sperlich and Beaker, (2002) examined the two main functions of the strain gauges for the kayaking community. Firstly, they might be used for monitoring athletes' performance, with peak and mean forces being compared from test to test. The second use would be related to technique control: force data associated with a time graph would allow the athletes to identify instants of low force production. Performance improvements could be attained by the use of stroke force curves.

2.6. Other equipment and boat set-up

Improvements in kayaking equipment lose some of their effectiveness if they are not appropriately configured in agreement with the kayaker's characteristics. The equipment set-up not only plays a key role in the comfort of athletes when paddling but also is responsible for the prevention of potential injuries and effective production of force (Ong et al., 2005).

Traditionally in kayaking body dimensions have been used for the determination of the initial paddle length and set-up (Toro, 1986). On the contrary, the selection of the blade size depends on other factors like age, individual force, technique and flat water discipline (Alacid, 2009). Long blades increase the cost of paddling and tend to increase the recovery time, however, they generate greater forward propulsion (Gowitzke and Brown, 1986; Ong et al., 2005).

Kinanthropometric variables of elite kayakers have been studied for many purposes. By using a battery of kinanthropometric and physiological tests, Fry (1991) identified the variables that most strongly influence performance, which included height, sitting height, body mass and the sum of eight skinfolds. Additionally, these variables have been analysed individually through different Olympic Games in an attempt to identify an elite kayaker profile (Ackland et al., 2001; Ackland et al., 2003). Barrett and Manning (2004) examined the morphology of fifteen rowers in order to establish the relationship with kinematic, rigging set-up and performance parameters such as race time and oar peak force.

Due to the restrictions in boat length and shape the only modifications which can be made by the athletes in the craft are the adjustments related to the seat height and the distance between seat and footplate (Toro, 1986; Alacid, 2009). Ong (2005) examined the physical dimensions and the equipment set-up parameters of elite slalom and flatwater kayakers. From those data, individual models for equipment set-up were predicted through regression equations. A subsequent investigation analysed the effect of three different set-ups on kinematics by using these predictive equations (Ong et al., 2006). The results suggested that predicting boat set-up based on anthropometric parameters does not ensure significant performance improvements. Therefore, it is suggested that changing the preferred set-up occurs only in the case of having a good reason to do so, and doing it in off-season periods to allow familiarisation with those set-ups (Ong et al., 2005; Ong et al., 2006).

2.6.1. Footrest and seat forces

In kayaking, the athlete is seated while paddling with the knees slightly flexed (110-120º) and the feet placed on the footplate (with a foot angle of approximately 60-70º relative to the horizontal) (Sánchez and Magaz, 1993). Both the seat and the footrest play an important role regarding kayak kinetics and kinematics. The force generated by the paddler is transmitted to the boat through the footrest and the seat (Ong et al., 2005), with the specific technique used when paddling generating internal contact forces applied to both elements (Begon et al., 2008a).

A single stroke starts at the catch phase with a pushing action of the upper limbs. Subsequent actions involved trunk rotation combined with the pulling movement of the straightened upper limbs (Mann and Kearney, 1980; Logan and Holt, 1985). Additional pedalling actions against the footrest are performed by the lower limbs to facilitate the trunk rotation and the propulsion. During the pull phase of a single stroke the contralateral knee is slightly flexed meanwhile the ipsilateral knee is extended, generating internal forces against the footrest and contributing to the trunk rotation (Begon et al., 2008a; Begon et al., 2010)

In rowing the oar has a mechanical connection with the boat and the force produced by the athlete is not only transmitted to the boat through the body as in kayaking but through the mechanical connection as well. Additionally, the slide trolley makes the foot stretcher especially important in terms of performance. The internal force produced by the feet in contact with the footrest and the influence of the foot stretcher when rowing has been widely studied (Elliott et al., 1993; Caplan and Gardner, 2005). In kayaking the seat is fixed to the boat and the forces applied to the seat and footrest can be in opposite directions (Begon et al., 2008a). However, little research has been undertaken related to forces internal to the paddler/boat system. Petrone et al. (1998) analysed in situ normal forces through a dynamometric system, obtaining values ranging from -128 to 6 N and from -152 to 444 N for the seat and footrest, respectively, where the positive direction is the race direction. Petrone et al. (2006) noticed that as the stroke pace and trunk rotation were increased on-ergometer the normal force applied to the footrest seemed to increase or maintain its values. Different contact force results were obtained by Begon et al. (2008a), apparently caused by the different-level of their kayakers and the use of a sliding ergometer instead. The normal force oscillated from -42 to 815 N for the footrest and from -116 to 588 N for the seat. According to Begon et al. (2008a) the peak forces applied by the kayaker to their equipment peak in the sequence: paddle, foot and finally seat. The authors noticed that, in the first part of the stroke, those kayakers who used straps around the feet produced pulling actions in the footrest and seat allowing pelvis rotation. When the blade force attains its maximum value it is the decrease in seat forces that facilitates pelvis rotation (Begon et al., 2008a). In subsequent studies, Begon et al. (2010) investigated the contributions of the lower limbs to performance. Due to the technical difficulties in measuring the lower limbs during paddling on-water, pedalling motion was simulated from ergometer data. The lower limbs' action was estimated to increase the propulsive forces and the boat velocity, with a performance increase of around 6% per stroke. However, an understanding of the coordination of the internal forces generated in the seat-footrest-paddle system would require further investigation because the relationship between performance and contact force is not clear so far (Begon et al., 2008a; Begon et al., 2010).

2.6.2 Swivel seat

As mentioned above kayaking technique involves the combined action of not only the upper limbs but also the lower limbs and trunk rotation (Mann and Kearney, 1980). Although the forward motion is mainly generated by the upper limbs, trunk rotation significantly improves the propulsion during the pull phase of the stroke. The contribution from this rotation depends on the co-ordination of the pelvis with the upper and the lower limbs during the pedalling motion and on the time history of the pelvis angular velocity (Logan and Holt, 1985; Begon et al., 2010). Additionally, the "rounding out" stroke technique used with the wing paddle allows lateral paddle movements which involve the larger muscles of the trunk and make the action more physiologically economical (Sanders and Baker, 1998). Supporting this idea, Begon et al. (2010) calculated that the energy cost of each stroke increased by 20 J when the trunk remained motionless (around 4% of the total energy expenditure per stroke).

To facilitate trunk rotation and improve the mechanics of the stroke technique, a new seat called the "swivel seat" was designed. Although the swivel seat was created before 2005 the ICF did not authorise its use until that year. In contrast to the standard "fixed seat", the new design included a mechanism which allows it to freely rotate about its vertical axis, aiding the paddler's pelvic rotation. It might be hypothesised that with the introduction of the swivel seat the pedalling motion becomes more physiologically efficient. The rotational movements of the seat about the vertical axis would facilitate a more fluid trunk rotation. Additionally, the new design would facilitate the natural curve path followed by the wing paddle (Figure 4) and allow the entry of the blade to occur further forward (Michael et al., 2009; Michael et al., 2010).

To date, little research concerning the effects of the swivel seat on performance has been conducted. Petrone et al. (2006) analysed the effect of the swivel seat on kinematics and kinetics in five elite kayakers on-ergometer. Both the knee range of motion and the footplate forces were larger with the rotational seat than the fixed seat. The authors reported a more consistent trunk motion by the more successful elite paddlers when paddling with the swivel seat. However, they did not undertake either a comparison of the trunk rotation when using the two seats or any statistical analysis of the variables they did measure. Another limitation was the restricted number of participants recruited, which means the results must be treated with some caution. Michael et al. (2010) examined the physiological responses related to the use of different seats over a two-minute ergometer test. The greater effectiveness of the swivel seat was corroborated by greater power outputs obtained than with the fixed seat, without a significant increase in oxygen consumption. Thus, an alteration in technique was suggested to be the cause of an increase in stroke efficiency when paddling with a rotational seat.

Nevertheless, among the kayaking community there exist some disagreement about the real effect of the new seat design for on-water performance. It is commonly believed that the balance of the boat may be affected more than usual by the rotational movements of the swivel seat since its mechanism freely rotates and stop movements have to be performed. These movements may affect the body and hands' positions at the start of the stroke and would upset the boat stability especially around the longitudinal (rolling) and vertical axes (yawing). The drag forces acting on the hull would increase as a result of the increase in the instantaneous wetted area of the craft. Consequently, the boat displacement would be affected negatively (Jackson, 1995; Michael et al., 2009) (see section 2.1). Further research is needed not only in this particular situation but also in other cases in which recent techniques for analysing kinematics and kinetics might be combined to provide a better understanding of flatwater kayak performance. Thus the aim of the present study was to compare the kinematics and the trunk muscle activation between paddling on an ergometer with a swivel seat and a fixed seat.

3. Methodology

3.1. Participants

Nine sprint kayakers (5 male and 4 female) volunteered for this study. The mean age, mass and height were 29 ± 11 year (17-43 years), 69 ± 12 kg (57-89 kg) and 1.74 ± 0.06 m (1.67-1.84 m), respectively. All participants trained on regular basis, were experienced kayakers, including one who had competed at the World Championships, and were familiar with the use of kayak ergometers. Participants were asked to maintain their regular training sessions but to abstain from any other form of hard exercise for at least 24 hours before the test.

The study was approved by the Ethics Committee of the School of Sport and Exercise Science at the University of Lincoln. Informed consent was obtained from all participants of 18 years age or older; where participants were under 18, assent was obtained from the participant and consent from a parent.

3.2. Test procedure

Participants completed two trials on a kayak ergometer, one using a fixed seat and the other using a swivel seat. The order in which the seats were used was counterbalanced as far as possible; the withdrawal from the study of a tenth participant meant that five participants used the swivel seat first, and four used the fixed seat first. Before using each seat the participants were allowed to adjust the position of the ergometer footrest and then to familiarise themselves with the equipment and warm up for ten minutes. For each seat condition, participants were then asked to paddle at maximum velocity for 30 s at their choice of stroke frequency. A rest of approximately ten minutes was provided to the paddlers between the two seat conditions in order to ensure appropriate recuperation before the second test.

A free stroke frequency was selected for use during the trials as long as paddlers performed the test at maximum effort. Some previous research supports the idea of kinematic changes at different stroke paces (McGregor et al., 2004; Hofmijster et al., 2007; Sealey et al., 2011; Wassinger et al., 2011), thus imposing a pace on the participants might have influenced their technique.

3.3. Experimental set-up

All tests were performed in an indoor laboratory on a Lawler Paddling Machine kayak ergometer which consists of a paddle shaft with the cable running from each end back to either side of a flywheel (Lawler Engineering Ltd, East Moseley, Surrey, UK). The two kayak seats (Figure 6) that could be fitted to the ergometer were a standard, fixed racing seat (VASA; Essex, VT, USA) and a swivel seat which was able to rotate around the vertical axis (Nelo Rotating Carbon seat, M.A.R. Kayaks Lda, Vila do Conde, Portugal). During the maximum velocity tests, data regarding kinematic and muscle activity were collected simultaneously.

a b

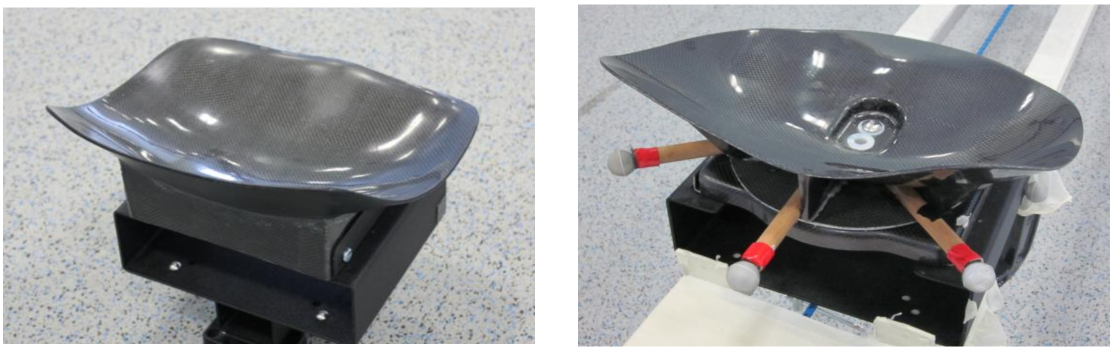

Figure 6 – Images of the **(a)** fixed seat and **(b)** swivel seat

Retro-reflective spherical markers with a diameter of 16 mm were used (Qualisys, Gothenburg, Sweden). The 3D coordinates of reflective markers on the body, paddle shaft and ergometer were captured at 200 Hz using eight Qualisys ProReflex MCU500 cameras and Qualisys Track Manager (QTM) computer software (Qualisys, Gothenburg, Sweden). Before every data collection session, a wand calibration (500 mm in length) was performed to ensure the proper reconstruction of marker location, and a calibration was accepted if the tracking residuals were below 0.4 mm. An L-shaped calibration frame was used to define an initial Global Reference Frame whose origin was at ground level below the centre of the ergometer. The Global Reference Frame was orientated so that the X_G-axis ran horizontal and parallel to the longitudinal axis of the ergometer, the Z_G-axis was vertical and the Y_G-axis was the cross product of Z_G and X_G.

Upper limb markers were attached bilaterally to the participant's skin using double-sided adhesive tape at the wrist (ulnar and radial styloid processes), elbow (medial and lateral humeral epicondyles), and shoulder (acromion process, anterior and posterior shoulder). Trunk markers were placed anteriorly at the jugular notch and posteriorly over the spinal processes of the C5 and T10 vertebrae. Pelvic markers were placed bilaterally on the iliac crest, ASIS and PSIS to reproduce the pelvis motion and determine its rotation relative to the trunk and the ergometer. Lower limb markers were placed at the hip bilaterally (greater trochanters), the knee (lateral femoral epicondyle) and the ankle (lateral malleolus). Two clusters of markers were attached to the paddle shaft, either side of the centre of the shaft and inside the hand positions. One of these clusters contained three markers and the second contained two; all five markers were attached to the end of 65 mm pegs extending from the shaft. Taking the ergometer seat as a reference, markers were placed anteriorly and posteriorly on the left and right ergometer beams to help define an ergometer-based reference frame. To accurately monitor paddling speed in terms of revolutions per minute, a marker was placed on the ergometer flywheel halfway between the edge and the centre. The time taken by the marker to complete three turns was used to calculate the revolutions per minute.

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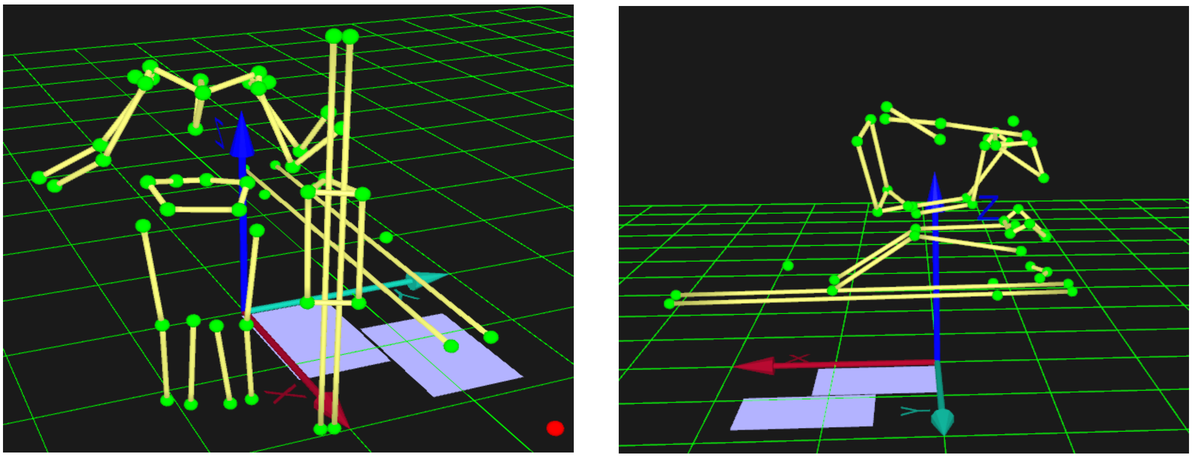

Figure 7 – Screen images of the marker positions during **(a)** the static and **(b)** the dynamic trials.

Prior to the dynamic trial for each seat, a static trial was recorded, during which supplementary markers were placed either side of the tip at each end of the paddle shaft (Figure 7). These markers were removed prior to the dynamic trials, where they would have been knocked off by the ergometer cable, but they were used in the subsequent reconstruction of the paddle tip motion during those trials (as described below).

During the paddling trials, electrical activity of selected trunk muscles was measured simultaneously using a wireless surface electromyography system (Myomonitor IV Wireless EMG System, Delsys Inc., Boston, MA, USA). Single differential sensors with 1cm spacing between parallel bars (DE-2.1, Delsys Inc., Boston, MA, USA) were affixed over the skin of the muscles involved. The Common Mode Rejection Ratio (CMRR) of the amplifiers was >92 dB with an input referred mode of 1.5 rms and a gain of 1000. Data were collected at 1000Hz using EMGworks 4.0 software (Delsys Inc., Boston, MA, USA).

Prior to placing the electrodes, the skin of the participants was prepared by dry shaving, as necessary, followed by vigorous rubbing with an alcohol swab and air drying. Electrodes were placed as follows, after McGill (1991) and Cram and Criswell (2010): on the erector spinae, 4 cm laterally from the T12 spinous processes; on the latissimus dorsi, 4 cm below the inferior tip of the scapula, at an oblique angle of 25º and half the distance between the lateral edge of the torso and the spine; on the rectus abdominis, 3-4 cm laterally from the abdominal midline and 5 cm above the umbilicus; on the external obliques, half the distance between the anterior superior iliac spine and the ribs and at a slightly oblique angle with respect to the abdominal midline; and on the internal obliques, below and slightly medial to the external oblique electrodes and just superior to the inguinal ligament. All muscles were analysed bilaterally to allow identification of any potential differences between the body sides and for consideration alongside any observed bilateral differences in kinematics. Additionally, a ground electrode (Dermatrode HE-R, American Imex, CA, USA) of 5.08 cm diameter was situated on the patella. From pilot studies the selection of muscles was made based on the level of activation and their participation in trunk rotation. When the electrode placement compromised the paddler's mobility during pilot tests these muscles were not selected for subsequent use.

3.4. Data analysis

All markers were identified in the static and dynamic trials using Qualisys Track Manager (Figure 7) and their 3D coordinates were exported to MATLAB 7.0 (MathWorks, Natick, MA, USA) for further processing. The (x_G, y_G, z_G) coordinates were first transformed into an ergometer-based reference frame in which the positive X direction of the coordinate system was defined as horizontal, parallel to the longitudinal axis of the ergometer and pointing forward; the positive Z direction was vertically up; and the positive Y direction was mediolateral, pointing to the participant's left.

In each frame of the static trials, a virtual paddle tip at each end of the shaft was calculated as the point halfway between the two markers at that end of the shaft. The average positions of these mid-tip marker position were determined in a paddle-based coordinate system defined using the five cluster markers on the paddle. These offsets and the instantaneous locations of the cluster markers were then used to reconstruct the position of the paddle shaft mid-tips in each frame of the dynamic trials. The mid-wrist and mid-elbow joint centres were calculated as halfway between the lateral and medial markers

The three coordinate values for each marker were separately smoothed using a double-pass 4^{th}-order Butterworth low-pass filter with zero phase lag and a cutoff of 10 Hz. To facilitate the analysis of the stroke, two key events were identified: the "catch" defined by the instant at which the x-coordinate of the paddle tip reached its most positive value and the "exit" when the most negative value was reached by the paddle tip (Michael et al., 2010).

Only ten cycles of each 30-s trial were selected to be tested (Petrone et al., 2006). The first 10 s were excluded from examination as they were considered to be an acceleration phase up to the steady competition velocity (Telford, 1982). The ten selected cycles started with the first "catch" with the right hand after this initial 10 s period.

The mean and peak mean values of the flywheel speed, paddling stroke rate (SR), recovery time, drive time, paddle time to 90º (see below), paddle tip range of motion

(ROM) during the drive, paddle tip ROM to 90º and paddle tip lateral displacement were determined as a measurement of performance during the maximal test based on previous studies (Plagenhoef, 1979; Mann and Kearney, 1980; Kendal and Sanders, 1992; Ong et al., 2006; Fleming et al., 2012; Michael et al., 2012) . The paddling stroke frequency was calculated in strokes per minute across ten cycles with the stroke defined as running from one side blade entry to opposite side blade entry. The drive phase was described as the phase between the paddle entry to same side blade exit. The 90° paddle event was defined for each stroke as the time when the projection of the shaft onto the XZ plane was perpendicular to the X axis in each stroke. Mean drive time and ROM, as well as mean time and ROM to 90º were analysed with reference to the reconstructed paddle tips. Additionally the tip ROM was measured as the tip distance from paddle entry to same side exit

The technique parameters were obtained bilaterally from paddle, elbow and knee angles. Mean paddle catch and exit angle relative to the XZ plane were obtained (López and Ribas, 2011; Fleming et al., 2012). Also knee and elbow angle at catch and exit were examined, along with their ROM over the cycle (Kranzl et al., 1996; Baker et al., 1999; Petrone et al., 2006; Espinosa, 2011; López-Plaza et al., 2012), the ROM between the catch and exit (Petrone et al., 2006), and the maximum and minimum values for each joint during drive phase. Since the anterior and middle elbow markers were partially obscured during the recordings, elbow joint angles were obtained from the posterior shoulder, the mid-wrist and mid-elbow points. Given the nature of the paddling motion, there was too much occlusion of the anterior shoulder and acromion markers, therefore, only the posterior shoulder markers was used for the determination of the elbow joint angle. Similarly, knee angle was calculated by the lateral markers situated on the malleolus, femoral epicondyle and greater trochanter. According to Petrone et al., (2006) trunk rotation was examined using a line between the posterior shoulder markers due to the technical problems with tracking the three trunk markers simultaneously. To define pelvis ROM, the two markers placed on the iliac crests were used to construct a pelvis line. All rotation angle calculations were determined from the angle between the Y axis and the projection of the shoulder or pelvis line onto the XY plane.

To obtain the mean values for each parameter, the mean of the ten cycles was calculated for each participant and then the mean of these values was determined across all participants. The resultant mean values were used for comparisons between the two paddling conditions.

Raw EMG signals were amplified, A/D converted and band pass filtered between 20 and 450 Hz (roll-off of 80 dB/dec) by the hardware. All signals were smoothed in MATLAB using a double-pass 4^{th}-order Butterworth low-pass filter with zero phase lag and a cutoff frequency of 10 Hz. The amplitude of each signal was determined for each trial using the root mean square (RMS) voltage across the ten cycles. To facilitate the comparison between conditions, each muscle's activation during the swivel seat trial was represented as a percentage of the corresponding fixed seat activation. Sweating was a particular problem during the trials and complicated the adhesion of the electrodes. Where an electrode signal was compromised at any point in the recording period, that signal was excluded from subsequent analysis (14 out of 90 EMG signals). Based on pilot studies, the use of Maximum Voluntary Contractions was rejected due to the possibility of electrode displacement during the process, which might have compromised the subsequent data collection during the paddling trials. Since the main focus of the investigation was the comparison of muscle activity between the two seats, rather than the comparison of muscles within each seat condition, it was decided that raw amplitudes would be compared.

3.5. Statistical analysis

All statistical analyses were conducted using SPSS v19 (SPSS Inc., Chicago IL). The normality of the distribution of the values for each variable was investigated using Shapiro-Wilk tests. Where the assumption of normality was not violated, the difference between the mean values for the two seat conditions was analysed using paired t-test; Wilcoxon's tests were conducted for variables which showed a non-normal distribution. Statistical significance was set at $p < 0.05$. Adjustment of the significance level for multiple testing was not undertaken so as to avoid an increased risk of Type II error (Perneger, 1998). Cohen's *d* was used to measure the effect size of observed differences, with the standard deviation pooled from the swivel and fixed seat data. The effect size was considered small between 0.2 and 0.5, moderate between 0.5 and 0.8, and large when the effect was > 0.8.

4. Results

4.1. Performance variables

Performance variable results are summarised for each condition (fixed and swivel seat) in Table 1. Peak flywheel RPM values were significantly higher (p = 0.033) for the swivel seat than the fixed seat, with a difference between means of 28.8 ± 33.6 rpm. Although the difference between means of 18.25 ± 24.06 rpm did not reach statistical significance greater mean flywheel RPM in the swivel seat condition. Analysis of the mean paddle ROM until 90º and the drive ROM over both body sides indicated significant differences ($p < 0.05$), with greater right side ROM in both cases during the swivel seat trial but a relatively small size of the effects (d = 0.11 and d = 0.27 respectively). Paired t-tests revealed shorter paddle recovery times with the use of swivel seat, especially for the right side (differences between means: 0.02 ± 0.02 s, p = 0.043). The use of the swivel seat also resulted in mean and peak stroke rate (SR) increases relative to the fixed seat but none of these differences were significant showing small effect size values (Cohen's d = 0.30 and 0.33, respectively). Mean drive time and paddle time to 90º are also presented for both right and left strokes in Table 1. Although the differences were non-significant except for the left drive (p = 0.049), slightly shorter stroke times can be noted for the rotational seat condition for both body sides. Similarly, shorter lateral displacements of the paddle were observed with the swivel seat, especially on the right side where the difference between means was 19.7 ± 39.6 mm.

Table 1 – Mean values of performance parameters during the ten analysed cycles from a maximal test on ergometer with the swivel and fixed seat

	Fixed seat (n=9)	Swivel seat (n=9)	Paired Differences				p - value	Effect size (Cohen's d)
			Mean ± SD	Std. Error Mean	95% Confidence Interval			
					Lower	Upper		
Mean flywheel speed (rev min $^{-1}$)	1029.4 ± 117.5	1047.5 ± 116.7	-18.3 ± 24.1	8.02	-3.67	0.25	0.052	0.16
Peak flywheel speed (rev min $^{-1}$)	1056.7 ± 127.0	1085.5 ± 129.7	-28.8 ± 33.6	1.12	-5.46	-2.93	**0.033***	0.22
Mean SR (stroke min $^{-1}$)	125.0 ± 11.9	128.4 ± 11.1	-3.39 ± 4.81	1.60	-7.08	0.31	0.067	0.30
Peak SR (stroke min $^{-1}$)	128.5 ± 12.7	132.7 ± 12.6	-4.15 ± 6.72	2.24	-9.32	0.01	0.101	0.33
R recovery time (s)	0.50 ± 0.05	0.48 ± 0.04	0.02 ± 0.02	0.01	0.01	0.04	**0.043***	0.44
L recovery time (s)	0.49 ± 0.06	0.48 ± 0.05	0.01 ± 0.02	0.01	-0.01	0.02	0.225	0.18
R drive time (s)	0.47 ± 0.06	0.46 ± 0.05	0.01 ± 0.02	0.01	0.01	0.02	0.152	0.18
L drive time (s)	0.48 ± 0.05	0.46 ± 0.04	0.02 ± 0.02	0.01	0.01	0.03	**0.049***	0.44
Time to 90º - right stroke (s)	0.19 ± 0.04	0.18 ± 0.04	0.01 ± 0.01	0.01	-0.01	0.01	0.287	0.25
Time to 90º - left stroke (s)	0.20 ± 0.03	0.19 ± 0.03	0.01 ± 0.01	0.01	-0.01	0.02	0.102	0.33
R drive ROM (mm)	1372.3 ± 86.4	1395 ± 83.8	-23.15 ± 22.63	7.54	-40.55	-5.76	**0.015***	0.27
L drive ROM (mm)	1437.7 ± 115.6	1411.4 ± 112.2	26.33± 33.35	11.12	-0.7	51.97	0.056	0.23
ROM to 90º - right stroke (mm)	731.7 ± 149.2	752.3 ± 143.9	-16.2 ± 19.9	6.65	-31.55	-0.89	**0.041***	0.11
ROM to 90º - left stroke (mm)	766.6 ± 117.2	765.5 ± 117.5	6.54 ± 11.4	3.79	-2.19	15.28	0.122	0.06
R paddle lat displac. (mm)	465.9 ± 124.2	446.2 ± 115.8	19.7 ± 39.6	13.20	-10.76	50.11	0.174	0.16
L paddle lat displac. (mm)	485.8 ± 110.9	484.9 ± 99.0	0.9 ± 53.3	17.76	-40.06	41.86	0.961	0.01

Group means ± SD, the difference between the means ± SD, the SE mean and the lower and upper bound 95 % confidence intervals for the differences between means.
* indicates a significant difference $p < 0.05$

Table 2 - Percentage of each paddle phase within the cycle for the right and left side.

	Drive phase (%)		Recovery phase (%)		Time to 90º (%)	
	Fixed	Swivel	Fixed	Swivel	Fixed	Swivel
Right side	48.5	47.9	51.5	52.1	19.6	19.1
Left side	49.5	47.8	50.5	52.2	20.4	19.6

4.2. Technique variables

Table 3 presents the values of the paddle angle parameters for each seat condition and body side. No significant differences were found for paddle angle either at entry or exit. Conversely, paired t-test analysis of the knee angles in Table 4 revealed significantly more knee flexion at catch and more extension at exit on both sides with the swivel seat ($p < 0.05$). The effect sizes were 0.5 or more in all cases. Analysing the knee joint ROM from catch to exit, significantly larger ranges of motions were observed when using the swivel seat ($p < 0.05$). Additionally, significant differences also occurred for minimum knee angle for both body sides and for maximum right knee angle. Cohen's d calculation revealed small and moderate effect sizes for all these parameters, which were observed to have more acute and more obtuse angles for minimum and maximum knee angle, respectively, under the swivel condition. Meaningful differences were found between the two seats for the elbow parameters (Table 5). Greater range of motion was observed in the swivel seat trials but none of these differences was statistically significant (74.5 ± 23.7 vs 79.8 ± 14.2 and 68 ± 21.3 vs 75.5 ± 17.9º for the right and left elbow, respectively). Similarly, larger but non-significant values were found for maximum and minimum left elbow angle whereas lower angles were observed on the right side during the swivel seat trial. Figure 6 shows a typical example of how the timing of the paddle-defined stroke events relates to the timing of the knee angle events.

Table 3 - Mean values of technique parameters during the ten analysed cycles from a maximal test on ergometer with the swivel and fixed seat

	Fixed seat (n=9)	Swivel seat (n=9)	Paired Differences				*p* - value	Effect size (Cohen's *d*)
			Mean ± SD	Std. Error Mean	95% Confidence Interval			
					Lower	Upper		
Mean R paddle catch angle (º)	-0.07 ± 2.31	0.42 ± 2.23	-0.49 ± 0.89	0.30	-1.18	0.19	0.136	0.26
Mean L paddle catch angle (º)	1.20 ± 2.44	0.79 ± 2.15	0.41 ± 1.49	0.50	-0.74	1.56	0.434	0.17
Mean R paddle exit angle (º)	3.56 ± 1.69	4.03 ± 1.43	0.48 ± 1.86	0.62	-1.91	0.95	0.463	0.15
Mean L paddle exit angle (º)	6.72 ± 1.56	6.36 ±1.21	0.36 ± 2.11	0.70	-1.26	1.98	0.624	0.26

Group means ± SD, the difference between the means ± SD, the SE mean and the lower and upper bound 95 % confidence intervals for the differences between means.
* indicates a significant difference $p < 0.05$

Table 4- Mean values of knee parameters during the ten analysed cycles from a maximal test on ergometer with the swivel and fixed seat

	Fixed seat (n=9)	Swivel seat (n=9)	Paired Differences				*p* - value	Effect size (Cohen's *d*)
			Mean ± SD	Std. Error Mean	95% Confidence Interval			
					Lower	Upper		
Mean R knee angle (º)	144.6 ± 4.9	144.6 ± 4.7	0.03 ± 1.95	0.65	-1.47	1.53	0.962	0.00
Mean L knee angle (º)	143.4 ± 8.1	143.4 ± 7	0.07 ± 2.09	0.70	-1.53	1.68	0.921	0.01
Mean R knee ROM (º)	40.0 ± 16.8	36.5 ± 9	3.52 ± 17.78	5.93	-10.14	17.19	0.569	0.27
Mean L knee ROM (º)	39.0 ± 16.9	37.5 ± 6	1.49 ± 16.80	5.60	-11.43	14.41	0.797	0.13
Mean R knee catch angle (º)	132.1 ± 4.9	129.3 ± 5.4	2.76 ± 2.71	0.90	0.67	4.84	**0.016***	0.54
Mean L knee catch angle (º)	130.4 ± 7.6	128.4 ±7.6	2.04 ± 2.22	0.74	0.33	3.75	**0.011***	0.27
Mean R knee exit angle (º)	157.1 ± 6.9	159.9 ± 6.2	-2.82 ± 2.06	0.69	-4.40	-1.23	**0.003***	0.43
Mean L knee exit angle (º)	155.7 ± 10.2	158.6 ± 9.1	-2.89 ± 3.53	1.18	-5.60	-0.18	**0.039***	0.30
Mean R knee catch-exit ROM (º)	25.1 ± 6.4	30.6 ± 4.7	-5.53 ± 2.99	1.00	-7.80	-3.24	**0.008***	1.01
Mean L knee catch-exit ROM (º)	25.2 ± 6.6	30.2 ± 6.9	-4.99 ± 2.25	0.75	-6.72	-3.26	**<0.001***	0.74
Max R knee drive phase angle (º)	163.0 ± 8.3	165.4 ± 6.7	-2.44 ± 2.44	0.81	-4.31	-0.56	**0.017***	0.32
Max L knee drive phase angle (º)	161.8 ± 11.1	163.5 ± 9.5	-1.71 ± 2.64	0.88	-3.74	0.32	0.088	0.17
Min R knee drive phase angle (º)	132.0 ± 5	129.3 ± 5.4	2.74 ± 2.68	0.89	0.69	4.81	**0.015***	0.53
Min L knee drive phase angle (º)	130.5 ± 7.5	128.3 ± 7.5	2.18 ± 2.2	0.73	0.49	3.87	**0.011***	0.29

Group means ± SD, the difference between the means ± SD, the SE mean and the lower and upper bound 95 % confidence intervals for the differences between means
* indicates a significant difference $p < 0.05$

Table 5- Mean values of elbow parameters during the ten analysed cycles from a maximal test on ergometer with the swivel and fixed seat

	Fixed seat (n=9)	Swivel seat (n=9)	Paired Differences				*p* - value	Effect size (Cohen's *d*)
			Mean ± SD	Std. Error Mean	95% Confidence Interval			
					Lower	Upper		
Mean R elbow angle (º)	128.2 ± 5.6	126.7 ± 4	1.67 ± 3.85	1.36	- 1.55	4.88	0.208	0.35
Mean L elbow angle (º)	129.1 ± 2.9	129.4 ± 3	-0.34 ± 0.94	0.33	-1.13	0.45	0.343	0.11
Mean R Elbow ROM (º)	74.5 ± 23.7	79.8 ± 14.2	-5.23 ± 17.69	5.90	-18.83	8.37	0.401	0.28
Mean L Elbow ROM (º)	68.0 ± 21.3	75.5 ± 17.9	-7.5 ± 16.64	5.55	-20.29	5.29	0.213	0.38
Mean R Elbow catch angle (º)	153.8 ± 7.3	148.4 ± 12.3	5.33 ± 10.95	3.65	-3.08	13.75	0.182	0.54
Mean L Elbow catch angle (º)	153.6 ± 9	154.5 ± 8.9	-0.9 ± 1.4	0.47	-1.98	0.18	0.091	0.10
Mean R Elbow exit angle (º)	79.8 ± 12.7	82.15 ± 13	-2.38 ± 6.76	2,25	-7.57	2.82	0.322	0.19
Mean L Elbow exit angle (º)	84.7 ± 12.1	84.8 ± 11.6	-0.14 ± 2.76	0.92	-2.26	1.98	0.884	0.01
Mean R Elbow catch-exit ROM (º)	74.0 ± 17.6	66.3 ± 23.1	7.71 ± 16.81	5.60	-5.21	20.64	0.206	0.38
Mean L Elbow catch-exit ROM (º)	68.9 ± 19	70.0 ± 18.6	-0.76 ± 3.47	1.16	-3.43	1.90	0.529	0.04
Max R Elbow drive phase angle (º)	154.0 ± 7	151.6 ± 11.2	2.44 ± 6.45	2.15	-2.52	7.4	0.289	0.27
Max L Elbow drive phase angle (º)	155.4 ± 7.9	155.7 ± 8.3	-0.31 ± 1.33	0.44	-1.33	0.71	0.502	0.04
Min R Elbow drive phase angle (º)	79.8 ± 12.7	75.8 ± 14.6	3.96 ± 14.5	4.84	-7.19	15.11	0.441	0.29
Min L Elbow drive phase angle (º)	84.7 ± 12.1	84.8 ± 11.6	-0.14 ± 2.76	0.92	-2.26	1.98	0.884	0.01

Group means ± SD, the difference between the means ± SD, the SE mean and the lower and upper bound 95 % confidence intervals for differences between means
* indicates a significant difference $p < 0.05$

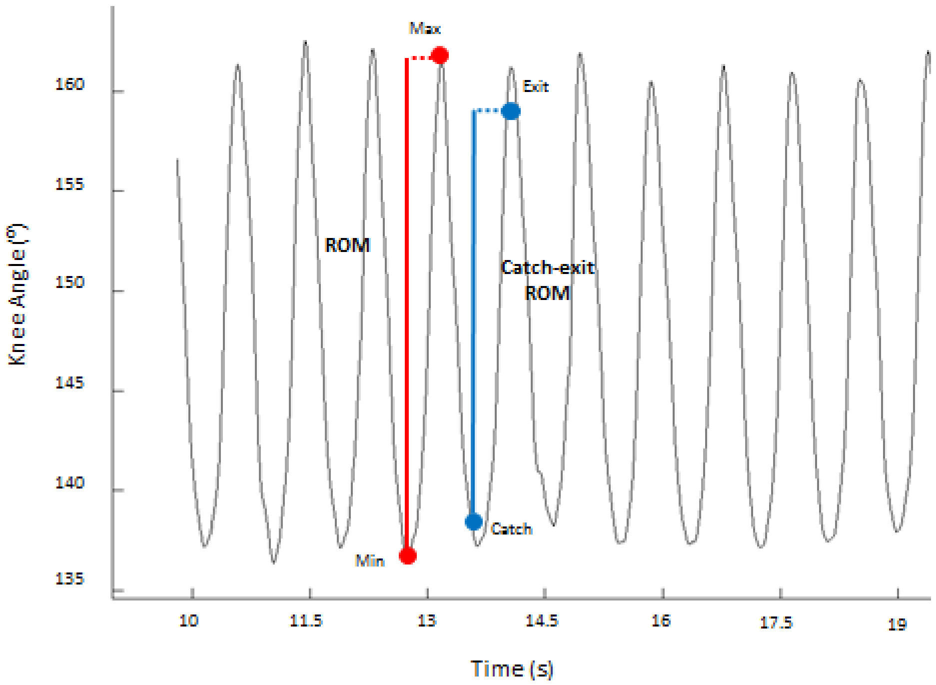

Figure 8 – Example of the time course of right knee angle changes of participant 9 when using the swivel seat, to illustrate their relationship to the timing of key stroke cycle events.

4.3. Trunk and seat rotation variables

Mean ROM values for the pelvis line, shoulder line and seat are presented in Figure 7 for each condition. Although a paired t-test revealed no significance (Table 6), mean shoulder ROM was greater in the swivel seat condition than in the fixed seat condition (108.7 ± 6.7 and 112.0 ± 6.6º, respectively). Significant differences between conditions occurred for the mean pelvis ROM, with larger values in the swivel seat condition ($p < 0.001$, $d = 0.58$). Analysing the shoulder-pelvis ROM difference when rotating to both sides, a significantly lower ROM was observed when using the swivel seat than the fixed seat (66.2 ± 4.9 and 63.0 ± 4.3º, respectively, $p = 0.019$, $d = 0.46$). Significantly lower pelvis-seat ROM values were detected by the paired t-test when paddling with the swivel seat (58.7 ± 11.9 and 36.6 ± 8.9º, respectively, $p < 0.01$, $d = 2.13$).

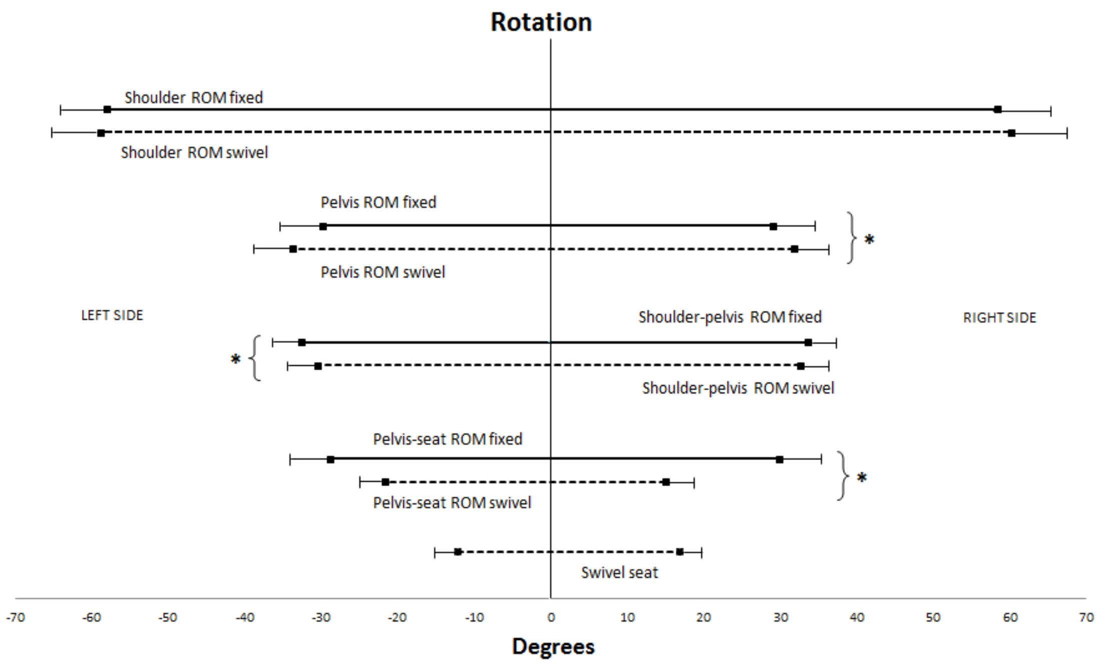

Figure 9 - Mean ± SD extreme angles for rotation about the vertical axis of shoulders, pelvis, shoulder-pelvis difference (trunk rotation), seat-pelvis difference and seat for both sides during the maximal test on ergometer. There was no rotation of the fixed seat.
* indicates a significant difference $p < 0.05$

Table 6 - Mean values of rotation during the ten analysed cycles from a maximal test on ergometer with the swivel and fixed seat

	Fixed seat (n=9)	Swivel seat (n=9)	Paired Differences				*p* - value	Effect size (Cohen's *d*)
			Mean ± SD	Std. Error Mean	95% Confidence Interval			
					Lower	Upper		
Shoulder ROM (º)	116.4 ± 14.0	119.0 ± 14.0	-2.55 ± 4.31	1.53	-6.16	1.06	0.076	0.18
Pelvis ROM (º)	58.9 ± 11.9	65.6 ± 11.6	-6.86 ± 2.92	1.03	-9.30	-4.41	**<0.001***	0.58
Shoulder-pelvis ROM (º)	66.2 ± 6.7	63.0 ± 7.3	3.19 ± 2.67	1.00	0.72	5.66	**0.019***	0.46
Pelvis-seat ROM (º)	58.9 ± 11.9	36.6 ± 8.9	22.14 ± 5.16	1.82	26.45	17.82	**<0.001***	2.13

Group means ± SD, the difference between the means ± SD, the SE mean and the lower and upper bound 95 % confidence intervals for shoulder, pelvis, shoulder-pelvis and pelvis-seat range of motion.
* indicates a significant difference $p < 0.05$

4.4 EMG variables

The mean RMS amplitude of the selected trunk muscles involved in the trunk rotation during swivel seat paddling are shown in Figure 8 as percentages of the fixed seat values. Observing the back muscles (latissimus dorsi and erector spinae), meaningful differences were detected between conditions despite the right erector spinae amplitude in the swivel condition being more than 2.5 times that in the fixed condition.. As for the abdominals, during the swivel seat condition greater RMS was observed than during the fixed. The right and left external obliques in the swivel condition showed 171 and 122% of the fixed RMS respectively and the right and left internal obliques 104 and 107%. However, paired t-test analysis only revealed significant differences for the right rectus abdominis (p = 0.038).

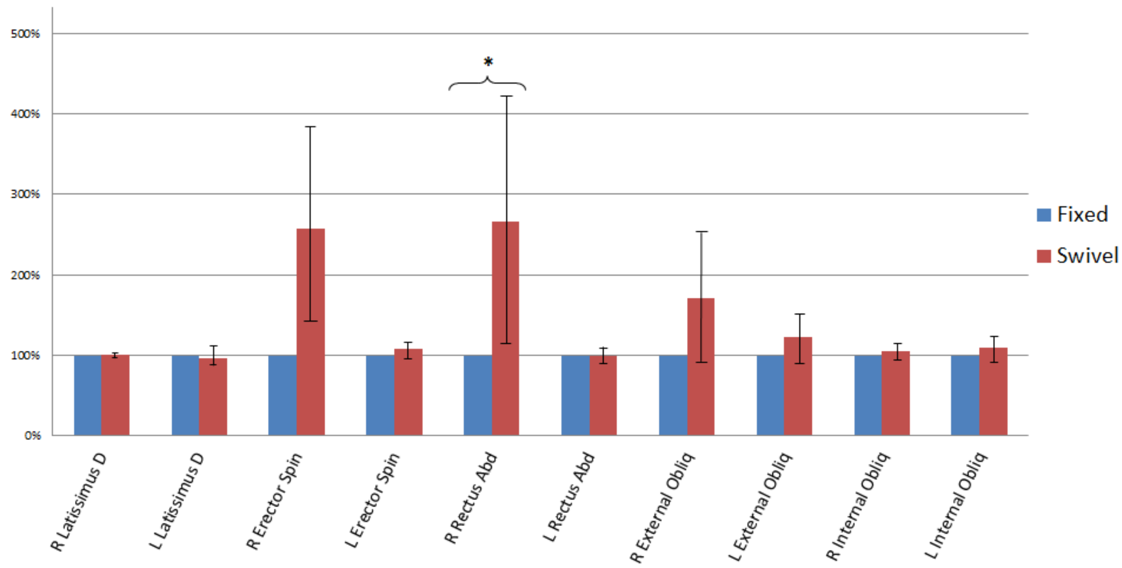

Figure 10 - Mean ± SD bilateral muscle activation of selected trunk muscles during the maximal test with swivel seat (red) normalized to the activation using the fixed seat (blue).
* indicates a significant difference $p < 0.05$

5. Discussion

The main purpose of the current study was to determine whether a kayak swivel seat influences kinematic parameters during a 30-s sprint on ergometer. The muscles involved in trunk rotation while paddling were also analysed in order to identify the differences in terms of activation. The hypothesis that a seat which freely rotates along its longitudinal axis would significantly change the kinematic parameters during paddling was supported. However, the secondary hypothesis that a swivel seat would significantly alter the activation levels of trunk muscles was not completely supported.

5.1 Performance parameters

Significantly greater flywheel RPM was observed when paddling with the swivel seat. During a kayak race, the winner is the first boat to cross the finish line and the present study results suggests that the use of the swivel seat might be associated with faster boat movement. Previous research has used power output as a measure of performance (van Someren and Dumbar, 1997; Bishop et al., 2001) and according to Michael et al. (2010) the required power output is proportional to the cube of kayak velocity. However, the wide range of ergometers involved present different power measures and this makes comparison between studies difficult (Colloud et al., 2006; Steer et al., 2006; Benson et al., 2011). Therefore, the flywheel RPM was selected for use as a measure of speed as it provides instantaneous information guaranteeing accuracy and repeatability between trials.

Another parameter which has been frequently studied as a determinant of optimum kayak performance is the stroke rate (Mann and Kearney, 1980; Michael et al., 2010). Paddlers in the present study had higher stroke rates during the swivel seat trials. Despite the non-significant nature of the difference between the two conditions, the results revealed about 4 strokes per minute more in the swivel seat condition. Since kayak velocity is the product of stroke rate and stroke length (Craig and Pendergast, 1979; Craig et al., 1985), the meaningful rise in SR would result in increasing boat velocity as paddle catch-exit ROM does not decrease significantly. On ergometer the stroke length is measured through the displacement of the paddle during the drive phase (catch-exit ROM) (Michael et al., 2012). In competition top performers have been seen to mainly use stroke rate rather than stroke length to increase velocity (Issurin, 1998). In addition better performances are traditionally associated with higher stroke rates as greater boat velocity is achieved (Sanders and Baker, 1998). However, overlooking stroke length while increasing stroke rate might be detrimental to boat displacement. The importance of the stroke rate is supported by the studies conducted by Hay and Yanai (1996) who found strong correlations between stroke frequency and boat velocity using a cross sectional design ($r = 0.75$) and also by Rath and Baker (1997) for 1000-m men ($r = 0.79$) and 500-m women ($r = 0.81$). Comparing the stroke frequency results with those from Michael et al. (2010) similar patterns were found. Although non-significant, greater values were obtained by Michael et al. (2010) when paddling using the swivel seat over a 2-minute ergometer test (109.6 and 110.4 strokes min^{-1} for fixed and swivel seat respectively). No research has been conducted yet into performance and kinematic parameters using the swivel seat on water, however, the few studies that have analysed stroke rate using the fixed seat reported values ranging from 100 to 140 strokes min^{-1} (Mann and Kearney, 1980; Logan and Holt, 1985; Ong et al., 2006), similar to those obtained here for the swivel and the fixed seat. In analyses of other on-water and cyclic sports, such as swimming, the same principle of a high correlation between stroke rate and velocity in elite performers can be observed (Klentrou and Montpetit, 1991).

Although few significant differences were detected in the parameters related to paddle timing, shorter phase times can be clearly observed from the swivel seat condition when compared with the use of the fixed one. The meaningful effect sizes support the importance of the differences especially for the right recovery time. Looking at both the greater stroke rates and shorter stroke phases both associated with the use of the swivel seat, a relationship between these parameters might be inferred. This is, the shorter the time taken to complete a stroke phase the greater the stroke rate and, as mentioned before, the faster the velocity. Additionally, Sanders and Kendal (1992) found negative correlation between all phase times and boat velocity.

The drive times, as a percentage of the complete cycle time, were lower in this study (values ranging from 47.8 to 49.5%) than those reported in the literature. Begon et al. (2008b) reported values ranging from 57 to 59% of the total cycle time for ergometer paddling. More variability is found in on-water investigations with a greater percentage (68-73%) observed from early studies (Plagenhoef, 1979; Mann and Kearney, 1980; Kendal and Sanders, 1992) and values closer to those in the present study identified in recent research (59-73%, Ong et al., 2006; 49%, Espinosa, 2011). According to Fleming et al. (2012) the moment when the paddle achieves the vertical position respect to the entry occurred slightly later on water (20-26% of the cycle time, Plagenhoef, 1979; Mann and Kearney, 1980); and 19-32% of the cycle time, (Ong et al., 2006) than on ergometer (22-24% of the cycle time, (Begon et al., 2003; Begon et al., 2008b). Also the results from the present investigation when using the swivel seat (19-20% of the cycle time) support the findings by Fleming et al. (2012) on ergometer. In canoeing (Caplan, 2009) and in kayaking this particular instant is especially important because the peak horizontal acceleration of the craft seems to occur near to paddle vertical position (Mann and Kearney, 1980; Logan and Holt, 1985; Michael et al., 2009) and slightly after the peak paddle force instant at approximately 40-45% of the drive phase time (Aitken and Neal, 1992; Fleming et al., 2012; Michael et al., 2012). Moreover, how rapidly the paddle is able to reach this point and how long the acceleration can be maintained is central to the attainment of optimal boat acceleration as peak paddle force and paddle vertical position seem to be associated (Mann and Kearney, 1980; Michael et al., 2009; Fleming et al., 2012).

The greatest difference from previous studies in terms of phase timing concerns the duration of the recovery phase between the exit and catch positions. Surprisingly, no other study has reported absolute and relative recovery times as long as those in the present investigation. Due to the sprint nature of the trials, shorter recovery times might be anticipated in order to reach higher stroke rates. It should be noted that stroke phase calculations were not determined by taking the same reference instants as most of on-water studies, thus, the comparison with those results should be made with caution.

Few conclusions can be drawn from examination of the displacement of the paddle tip in the X (antero-posterior) and Y (medio-lateral) directions since very different results were observed for the right and left sides, especially in the antero-posterior translation. Significantly greater values were found in the swivel seat condition for the right side while, conversely, the left side showed smaller but non-significantly different values in the same condition. These particular results may be due to the fact that 8 out of 9 paddlers were right handed and the larger application of force by this side during the pull phase may be associated with shorter displacements in X and Y directions on the right side. Unfortunately, no strain gauges or any other method to measure paddle force application could be used, therefore, this possibility cannot be investigated further. Supporting this idea, Michael et al. (2012) found shorter stroke length on the right side (1.23 m for right vs 1.25 m for left stroke) which were associated with greater peak paddle force (307.9 and 299.2 N for right and left side, respectively), although whether the participants were right or left handed was not indicated. Analysing the current results, it appears that the use of the swivel seat reduces these differences between right and left sides in terms of antero-posterior translation. Previous studies also analysed the displacement of the paddle tip in X direction on water and reported different values than those from the present investigation (1.37-1.43 m). Kendal and Sanders (1992) and Sanders and Baker (1998) found values ranged from approximately 1.50 to 1.70 m and Espinosa (2011) shorter translations (1.25 to 1.40 m). However, these comparisons must be treated with some caution as the length of the paddles used in the studies was different.

Similar medio-lateral paddle displacement was observed in the present study for swivel and fixed seat (0.45-0.49 m), with these values in agreement with those described by Kendal and Sanders (1992) on water (0.37 to 0.70 m) and López and Ribas (2011) on ergometer (0.33 m). Larger lateral displacements might be beneficial to propulsion as moving the paddle away from the boat directs the force more in a forward direction due to the lift forces acting on the blade and maintains a better blade vertical orientation for longer (Sanders and Baker, 1998; Robinson et al., 2002). Nevertheless, comparisons among on-water and on-ergometer results should be analysed with caution because, during on-ergometer paddling hydrodynamic forces do not affect the displacement of the paddle in the same way as occurs on water.

5.2. Technique parameters

The use of a predicted water surface height in the determination of paddle catch and exit angle was rejected due to the differences in boat set-up configurations and paddling positions among paddlers (Caubet, 1999; Ong et al., 2005). Following Michael et al. (2012), the "catch" and "exit" were defined as the instants at which the paddle tip reached its most positive and negative x-coordinates, respectively. The paddlers in the current study reached the most positive value (catch point) at the start of the stroke. Consequently, relatively low catch angles (the angle between the paddle and the horizontal at the most positive paddle x-coordinate) were obtained (0-1º) which suggests a premature "anticipated catch" probably caused by this method of defining the events. Michael et al. (2012) also reported low entry values (9.4 and 13.9º for left and right sides, respectively) by using the same method in the determination of paddle attack angles. In an attempt to define the optimal kayaking technique, Plagenhoef (1979) determined an angle of between 30 and 40º as optimal for entry on water while López and Ribas (2011) found it was 36º on ergometer. Similar values were observed from Fleming et al. (2012) when comparing on-water (43º) and on-ergometer (44º) paddle angles but water surface line estimation was used for their determination indoors. As was indicated before, one of the determinants in the generation of greater paddle forces is the paddle entry angle in the XZ plane. Previous studies have suggested changing the blade orientation with respect to the shaft to allow a more vertical angle of the blade for longer during the drive phase (Gowitzke and Brown, 1986; Robinson et al., 2002). During the first stages of the stroke this is even more important especially with the use of the wing paddle. The curvature of the wing blade causes separated flow from the blade tip resulting in high drag coefficients at large angles of the entry (Sumner et al., 2003). Therefore, higher attack angles would involve larger initial propulsive forces (Michael et al., 2012) and prevent large vertical forces that might result in detrimental pitching movements of the boat (Mann and Kearney, 1980).

As regards the paddle's exit angle, Baker et al. (1999) reported that the shaft exited the water at approximately 26-27º, in contrast with the values described in the current study which did not exceed 7º. As has been indicated before concerning catch angle, these discrepancies might be due to the different method in the determination of these events. Although traditionally little further attention has been given to exit angles in the literature, Mann and Kearney (1980) recommended withdrawing the paddle rapidly from the water once the blade has passed the vertical. No clear conclusions can be inferred from the present study's results as the timings of the events at which the entry and exit paddle angles were measured seem to have been different from the on-water cases.

No significant differences were found between the two seat conditions in the mean knee angles or knee ROM, in what appears to have been the first investigation of these parameters. Few authors have examined these variables as a determinants of performance but they have been mentioned as a part of paddling descriptions in manuals and technique guides (Sánchez and Magaz, 1993) and in descriptive studies (Petrone et al., 2006). Sanchez and Magaz (1993) pointed out that standard knee angle varied between 110 and 140º, giving range of motions ranged between 30 and 40º. Despite the lack of statistical analysis, Petrone et al. (2006) reported higher ROM values when paddling on ergometer using a rotational than a fixed seat (65-72º vs 63-66º respectively).

Although mean knee ROM showed no significant differences, further analysis of knee angle revealed that the use of the swivel seat resulted in significantly larger ROM from paddle entry to exit points. Lower knee angle values at entry combined with greater knee angle at exit resulted in approximately 5º ROM difference between the two seat conditions. Surprisingly, at paddle entry, knee angle has been the only kinematic variable where significant differences were found when paddling at different stroke paces (López-Plaza et al., 2012). This finding, in agreement with those reported in the current investigation, might suggest that knee joint angle may represent a parameter that is strongly affected if paddling action conditions are altered. The importance of the lower limbs alongside the upper limbs and pelvis rotation in a coordinated action, and their contribution to a fluid and synchronised stroke technique, has been widely stated (Mann and Kearney, 1980; Logan and Holt, 1985). According to Logan and Holt (1985) maximum knee flexion occurs just after the paddle blade entry. This suggestion is corroborated by the present investigation as two parameters - knee angle at catch and minimum knee angle between entry and exit - are almost identical to each other for both sides and conditions (see Table 4). Begon et al. (2010) calculated the contribution of lower limbs to performance and reported increases in about 6% in propulsion when their motions are properly coordinated with the trunk and upper limbs, especially in the central part of the drive phase. At this point the role of knee extensors associated with the abdomino-thorax rotators muscles become paramount in the generation of boat velocity (Begon et al., 2010; Fleming et al., 2012) as they especially contribute to paddling motion then. Thus, not involving the legs in the paddling motion might be damaging to performance (Begon et al., 2010).

In the determination of kayak technique, elbow angle has become one of the most important factors to look at when considering upper limb action (Mann and Kearney, 1980; Logan and Holt, 1985). However, surprisingly few authors have analysed this variable either in 2D (Sperlich and Baker, 2002; López-Plaza et al., 2012) or 3D (Ong et al., 2006; Espinosa, 2011), and there has been more focus on the joint path (Plagenhoef, 1979; Campagna et al., 1982; Lamb, 1989; Kendal and Sanders, 1992; Ho et al., 2009; Wassinger et al., 2011). No significant difference between the seats was identified for any elbow variable described in the present study or in the kayaking literature (Baker, 1998; Ong et al., 2006; López-Plaza et al., 2012). However the bilateral differences in elbow kinematics merit further mention. Greater mean, maximum and minimum elbow angle were observed for the left than for the right side, perhaps caused by the preponderance of right-handed paddlers (8 out of 9). These results are supported by Espinosa (2011) who described lower mean values not only for the right elbow (128.5º vs 137.9º for right and left elbow, respectively) but also for the right shoulder. Conversely, the elbow ROM was larger for the right side in the current investigation, which is also corroborated by Espinosa's results. This might suggest that paddlers rely more on elbow flexors (brachialis, biceps brachii and brachioradialis) and extensors (triceps brachii) when paddling on their preferred side. However, when observing the elbow ROM from entry to catch no differences can be noticed between sides, therefore, the greater use of elbow muscles must occur mainly during the recovery phase. A similar pattern occurs when comparing between conditions. Higher elbow ROM values were observed in the swivel seat condition whereas equal or lower ROM values were seen between the entry and exit. These results might indicate greater use of back rather than elbow muscles during the swivel seat drive phase, involving in turn less energetic cost (Sanders and Baker, 1998). In whitewater paddling the ROM values during the cycle reported by Kranzl et al. (1996) were quite similar (70º) to those reported in the current investigation.

Further research on the elbow angle at entry was undertaken because of the importance of this event. Although no differences in this parameter were detected between conditions in the current investigation, the range of values from 148 to 154º were similar to those found in the literature. On water, Baker et al. (1999) reported angles ranged from 144 to 148º while on ergometer Lopez-Plaza et al. (2012) found values around 159º with both studies conducted in 2D. Regarding exit elbow angle, contradictory results can be observed when this study's results are compared with those in the literature. Baker et al. (1999) in 2D and Ong et al. (2006) in 3D described on water values ranging 108 to 129º, quite different to those reported here (approximately 80-85º). These comparisons, however, should be treated with some caution because of the previously mentioned differences in the definitions of paddle entry and exit.

5.3. Rotation

Trunk rotation is another key element of the coordinated action which defines paddling (Logan and Holt, 1985; Begon et al., 2008a). The key feature that distinguishes the swivel seat from other seats is its ability to freely rotate about a vertical axis passing through its centre. In this study its use resulted in significantly greater rotational ROM of the pelvis than with the fixed seat and meaningfully greater ROM of shoulder rotation. This increase in shoulder rotation, especially at the right end of the range of motion, might be connected with the meaningfully larger paddle antero-posterior displacement previously noted in the same side. Comparing with prior research into shoulder rotation, lower ranges of motion (65-69º) were reported by Baker et al. (1999). As mentioned above, the use of the swivel seat also leads to an increase in both pelvis rotation and knee range of motion. Those parameters seem to be related to each other as both are determinants in the pedaling action performed by the lower limbs (Begon et al., 2010).

Contrary to the concept described by Shephard (1987), where trunk rotation is only defined by shoulder rotation, the present investigation defines trunk rotation as the shoulder ROM relative to the pelvis ROM. In the current study significantly lower values were observed for trunk rotation when using the swivel seat than the fixed seat (62.9 vs 66.1º). In further research on the trunk rotation during paddling on an ergometer with a swivel seat, Petrone et al. (2006) reported a wide range of trunk rotation values with the difference between shoulder and pelvis rotation ranging from 60 to 98º when paddling at 90 strokes min^{-1}. Elsewhere in the literature, upper body rotation about a vertical axis has been largely studied from an injury perspective (Veres et al., 2010; Chan et al., 2011). Too much torsion may cause excessively large torque to be applied to the spine, damaging the endplate and tubercular network of the vertebral body (Aultman et al., 2004). Furthermore, the long-term effects may include increases in nucleus pulpous pressure as well as the reductions in disc height (van Deursen et al., 2001). On the contrary, repeated cyclic torsion through smaller angles, as in the rotations observed when using the swivel seat, would involve improvements in nutrition and waste exchange that are beneficial to the intervertebral discs (Chan et al., 2011). Therefore, paddling using this type of seat might reduce the risk of spine injuries because of the lower trunk ROM values observed in comparison with the traditional seat.

During the swivel trials the seat rotated along its longitudinal axis through approximately 24º relative to the ergometer, with an asymmetry displaying slightly larger values on the right side. This greater right rotation is suspected to be associated with the significant increase in paddle antero-posterior displacement occurring on the right side when paddling with the swivel seat.

The only other study to date on the effects of the rotational seat on performance has been from a physiology perspective (Michael et al., 2010). When compared with the traditional seat no changes in oxygen consumption were detected whereas the power output was significantly higher with the rotational seat. As similar values were obtained for physiological parameters (VO_2, HR peak and lactate production) it was suggested that these improvements in performance might came from kinematics (Michael et al., 2010). While the swivel seat appears to facilitate increased boat speed among experienced paddlers it has been suggested that rotational seats might also have a detrimental effect on balance. The stability of the boat-paddler system might be affected by the rotation movements of the seat (Paddling.net, 2010). In an attempt to keep the balance in the craft, stabilising movements would be performed by the kayaker, involving additional energetic cost (Caplan and Gardner, 2008) and deviation from the paddling standard position. As a result, boat movements predominantly around the vertical (yawing) and longitudinal (rolling) axes (Wagner et al., 1993) might increase the instantaneous submerged area of the craft and generate detrimental drag forces acting on the hull (Baudouin and Hawkins, 2002). Maintaining a constant velocity of the boat has been seen to be the most efficient way to travel across the water (Mann and Kearney, 1980; Sanderson and Martindale, 1986; Michael et al., 2009) but balance corrections arising from the use of a swivel seat could result in larger instantaneous drag forces and fluctuations in kayak velocity.

5.4. EMG

The EMG amplitudes from the swivel seat condition were presented as percentages of the fixed seat muscle activation to facilitate comparison between the two conditions. Large standard deviations were observed for most of the variables, probably caused by the different skin thickness and subcutaneous fat of the paddlers (Cram and Criswell, 2010). In environments where additional electrical equipment is being used at the same time external noise may also influence the signal (Payton, 2008). Additionally, due to technical problems with skin adhesion and the high variability of EMG amplitudes more participants may be needed to investigate muscle activity properly. Further research in this area is needed with larger number of participants.

The results from the current study suggest that the use of the swivel seat may be associated with greater trunk muscle activation, especially in the ride side muscles. Greater right trunk muscle activity may be associated with the significantly increased seat rotation and paddle antero-posterior displacement (paddle ROM) described, and with the decreased time taken to perform these actions. Supporting this suggestion, the decreased right elbow ROM during the drive phase when using the swivel seat suggests greater engagement of the trunk muscles rather than the elbow flexors in the paddling action on that side. Brown et al. (2010) only found significantly greater activity in the latissimus dorsi among all trunk rotators and leg muscles during paddling. Although little previous research exists concerning kayaking and EMG, some investigations into the activity of the torso muscles during non-paddling activities have provided data for comparison. Marras et al. (1998) observed that the latissimus dorsi and external oblique abdominals decreased their activities during asymmetric twisting motions of the torso as the trunk flexion increased. Furthermore, the abdominals and erector spinae were more affected than any other torso muscle when the body position was modified, probably because they contribute to stabilising and balancing the trunk rather than generating axial torque (McGill, 1991; Marras et al., 1998; Urquhart and Hodges, 2005). Trunk rotator activity declined as the torso flexion and rotation increased probably because of shortening muscle length (Kumar et al., 1996, Aultman et al., 2004). These findings support those findings of the present study as in the swivel seat condition higher EMG was observed alongside significantly lower trunk rotation. In agreement with Marras et al. (1998) and Marchetti et al. (2011), the greater activity identified for the erector spinae and abdominals might suggest a change to a less flexed spine while paddling, associated with the use of the swivel seat. In addition, the nature of the swivel seat, with its free rotation about the vertical axis, might increase the role of the contralateral torso muscles. That is, the internal abdominals and erector spinae would contract eccentrically to stop the rotational movement of the seat and change direction. Further detailed research about timing and peak activity is needed to gain a better understanding of the trunk rotation process while paddling with the fixed and the swivel seat. Once again the results of the current project may suggest there is a greater activity in the muscles stabilizing the trunk while paddling with a rotational seat

5.5. Limitations and delimitations

A number of study delimitations arose from choices made in the design of the methodology:

- Both male and female participants were recruited and they were not elite kayakers. However, all participants were experienced kayakers who were familiar with the use of an ergometer and who train regularly for competition.

- The research was conducted indoors and on-ergometer rather than on the water because: a) the limitations of the biomechanical and the EMG equipment available did not allow the data collection to be conducted outdoors. The ProReflex cameras become saturated by the IR light in sunlight and the EMG devices were not waterproof; b) 30 s of paddling at maximal effort were needed, which could not be tracked when the paddler is moving. Commonly in water sports, results obtained indoors are translated to outdoors use.

- Although the Lawler ergometer used during the data collection was not equipped with a console to display any performance parameters digitally, this ergometer was selected rather than a KayakPro because it appears to better reproduce on-water kinematics. Based on feedback from high-level coaches the Lawler allows a more natural paddling motion, especially at the end of the "pull" phase and exit from the water. The Lawler also allows access to the flywheel, enabling its motion to be tracked. This is not possible with the KayakPro.

- Only a limited number of muscles were selected to be monitored. Possibly other muscles rather than the main trunk rotators could also have been affected by the choice of seat. Only the rotators were selected as it was anticipated that the swivel seat would more directly affect activity in these muscles. The location of certain electrodes would have interfered with body rotation and the paddling action by the arms. Additionally, the muscle activation was considered auxiliary information to support the kinematic findings.

During the research process some further methodological limitations arose, which led to a number of adjustments that have been described above:

- Some markers (i.e. the frontal and lateral shoulder markers) were obscured during certain phases of the paddling cycle. Similarly, the fast actions performed by the athletes caused some markers to come off during the trials. During the data analysis process, modifications were needed in calculating parameters such as knee angle and shoulder rotation.

- The use of Maximum Voluntary Contractions was rejected due to the possibility of electrode displacement during the activities used to invoke maximal contraction.

- Some participants sweated more profusely than had been observed with the paddlers used in pilot studies. Despite the electrodes being taped down, some problems arose with skin-electrode adhesion due to the intensity of the activity, and the data for some muscles had to be discarded.

- Potential crosstalk from the lumbar multifidis muscles on the erector spinae might have occurred during the EMG collection

5.6. Study implications

The present study has enhanced the current understanding of how the use of different seat designs affects kayaking performance and kinematics. Its findings regarding the use of swivel seat have a number of implications for coaches and biomechanists:

- For coaches, this is the first study to analyse the combined effects of the swivel seat on performance and kinematics. The use of this type of seat has been a controversial issue among coaches, and the data collected here will help to inform that debate. Moreover, some muscles heavily involved in the paddling motion have been confirmed and identified for targeting during strength and conditioning sessions.

- The combination of kinematic and surface electromyography data has been investigated for the first time using the swivel seat. Despite the problems with the EMG data collection, the potential for examining the relationship between these two factors has been demonstrated. Biomechanists can build upon these results, and consider more detailed exploration of the timing of kinematics and muscle activation.

- For athletes, this study has provided them with evidence about possible improvements in performance. Kayakers looking for new ways of enhancing their paddling will be better informed about the advantages and disadvantages of different seat designs.

- The results could encourage other manufacturers to start developing rotational seats, or allow those already producing this type of seat to improve their future designs.

5.7. Recommendations for future research

Future research should focus further on the temporal characteristics of the stroke: the coordination of kinematics and electromyography and how these parameters are temporally distributed along the cycle require detailed investigation. In addition, due to the difficulties encountered with the use of surface electromyography, the number of muscles studied was limited in the present study. For future investigations it is suggested that other muscles than just the main trunk rotators might be incorporated into any EMG analysis. As significant differences in knee angle parameters have been observed, leg muscles such as vastus lateralis or gastrocnemius might be examined.

Ideally, a similar study should be conducted on water to corroborate the findings of the present research in the actual environment where kayaking is practiced. As a result of the destabilising movements that may be associated with the swivel seat, introducing gyroscopes to future investigations on water might help to better understand the boat's behaviour. Additionally, valuable information might be provided by strain gauges placed on the paddle shaft. Force production data might be compared between conditions and between the two sides of the body, as some technique and performance parameters have been seen to be different between the dominant and non-dominant side.

More skilled kayakers have been seen to perform more consistent strokes (Petrone et al., 2006). In the data analysis the standard deviation of the EMG amplitudes might be reduced if only elite paddlers were selected. Moreover, further comparison between novice, experienced and elite kayakers would reveal how the activity of the rotators differs between groups.

6. Conclusions

The current study analysed the kinematics and torso muscle activation during paddling with two different types of racing seat, the traditional fixed seat and a swivel seat that is able to freely rotate about a vertical axis passing through its centre. Improvements in performance with the use of the swivel seat were detected through an increased flywheel RPM, peak stroke frequency and paddle horizontal displacement. Changes in technique were also observed, especially in the knee parameters. The rotational seat seems to significantly reduce the rotation of the trunk about its longitudinal axis (as measured by the rotation difference between shoulder line and pelvis) as well as to compensate the asymmetrical paddling technique differences in both sides determined during the fixed trials. Additionally, EMG analysis suggested greater activation of selected trunk muscles in the swivel seat condition, where the body position appeared to be modified to a more upright orientation. The reduced trunk rotation with the swivel seat may have benefits for paddler health alongside the performance enhancements observed in the present investigation.

These findings have relevance for coaches and paddlers since they suggest that the swivel seat may offer advantages in terms of enhancing kayaking performance and reducing the stress on the paddler’s back. Additionally, this is the first study to statistically analyse the effects of the swivel seat on kinematics and the results obtained may help designers in further developing this type of seat. However, more detailed investigation on water is needed to determine whether the application of the swivel seat under real conditions would produce similar benefits to those observed on ergometer. Simultaneous monitoring of boat movement using gyroscopes and accelerometers should be conducted to determine whether the magnitude of those displacements may affect the travelling boat velocity. Further analysis of the relative timings of paddle force application and muscle activation would also help to identify in greater detail the effects of the swivel seat throughout the cycle.

7. References

Ackland, T., Kerr, D., Hume, P., Norton, K., Ridge, B., Clarke, S., Broad, L. and Ross, W. (2001) Anthropometric normative data for Olympic rowers and paddlers. *Proceedings of the SMA Annual Scientific Conference.* Canberra, Sports Medicine Australia.

Ackland, T., Ong, K., Kerr, D. and Ridge, B. (2003) Morphological characteristics of Olympic sprint canoe and kayak paddlers. *Journal of Science and Medicine in Sport*, 6(3), 285-294.

Aitken, D.A. and Neal, R.J. (1992) An on-water analysis system for quantifying stroke force characteristics during kayak events. *International Journal of Sports Medicine,* 8, 165-73.

Alacid, F. (2009) Perfil antropométrico y cinemático del palista infantil [tesis doctoral]. Murcia, Universidad de Murcia.

Alacid, F., Isorna, M., Ferragut, C. and Torres, G. (2006a) Diferencias en cuanto a frecuencia de palada en un test de 30 segundos en kayakergómetro y en agua. Estudio preliminar. *IV Congreso de la Asociación Española de Ciencias del Deporte.* La Coruña, Universidad de La Coruña.

Alacid, F., Lopez-Minarro, P.A. and Isorna, M. (2010a) Pacing strategy and cycle frequency in canoeing at Beijing Olympic Games. *Revista Internacional de Medina y Ciencias de la Actividad Física y del Deporte,* 10(38), 203-217.

Alacid, F., López-Miñarro, P.A., Ferragut, C., García, A., Ferrer, V. and Martínez, I. (2008a) Evolución y comparación de la velocidad, frecuencia, longitud e índice de ciclo sobre 200 m, en palistas infantiles de diferentes modalidades. *Motricidad. European Journal of Human Movement*, 20, 15-27.

Alacid, F., López-Miñarro, P.A. and Vaquero, R. (2010b) Velocidad y frecuencia de ciclo en palistas infantiles en la distancia de 1000 m *Kronos: la revista científica de actividad física y deporte*, 9(17), 5-20.

Alacid, F., López-Miñarro, P.A., Vaquero, R. and Isorna, M. (2008b) Evolución de la velocidad y la frecuencia de ciclo sobre 1000 m en palistas infantiles. *II Congreso Internacional de entrenadores de piragüismo en aguas tranquilas.* Pontevedra, Universidad de Vigo.

Alacid, F., Torres, G., Sánchez, J. and Carrasco, L. (2006b) Validez de la ergometría en piragüismo. Estudio Preliminar. *Motricidad. European Journal of Human Movement*, 15(esp.), 119-127.

Arellano, R., Brown, P., Cappaert, J. and Nelson, R.C. (1994) Analysis of 50-, 100-,and 200-m freestyle swimmers at the 1992 Olympic Games. *Journal of Applied Biomechanics,* 10(2), 189-199.

Aultman, C.D., Drake, J.D., Callaghan, J.P. and McGill, S.M. (2004) The effect of static torsion on the compressive strength of the spine: an in vitro analysis using a porcine spine model. *Spine*, 29(15), 304-09.

Baker, J. (1998) Evaluation of biomechanical performance related factors with on-water tests. In: J. Vrijens (Ed.*), Proceedings of an International Seminar on Kayak-Canoe Coaching and Science (pp. 50–66),* Ghent, Belgium: International Canoe Federation.

Baker, J., Rath, D., Sanders, R.H. and Kelly, B. (1999) A three-dimensional analysis of male and female elite sprint kayak paddlers. *Scientific Proceedings of the International Society of Biomechanics in Sports – XVII International Symposium on Biomechanics in Sports.* Perth, Edith Cowan University.

Barnes, C.A. and Adams, P.C. (1998) Reliability and criterion validity of a 120 s maximal sprint on a kayak ergometer. *Journal of Sports Sciences,* 16(1), 26.

Barrett, R.S. and Manning, J.M. (2004) Relationships between rigging set-up, anthropometry, physical capacity, rowing kinematics and rowing performance. *Sports Biomechanics*, 3(2), 221-35.

Baudouin, A. and Hawkins, D. (2002) A biomechanical review of factors affecting rowing performance. *British Journal of Sports Medicine,* 36(6), 396-402; discussion 402.

Begon, M., Colloud, F. and Lacouture, P. (2008a) Measurement of contact forces on a kayak ergometer with a sliding footrest seat complex. *Sports Engineering,* 11(2), 67-73.

Begon, M., Colloud, F. and Sardain, P. (2010) Lower limb contribution in kayak performance: modelling, simulation and analysis. *Multibody System Dynamics,* 23(4), 387-400.

Begon, M., Lacouture, P. and Colloud, F. (2008b) 3D kinematic comparison between on-water and on ergometer kayaking. *ISBS Conference.* Seoul, Korea.

Begon, M., Mancini, G., Durand, F. and Lacouture, P. (2003) Comparison of kayak stroke kinematics on ergometer and in situ. *XXVIIIème Congrès de la Société de Biomécanique.* France, Archives of Physiology and Biochemistry

Begon, M., Mourasse, O. and Lacouture, P. (2009) A method of providing accurate velocity feedback of performance on an instrumented kayak ergometer. *Sports Engineering,* 11(2), 57-65.

Benson, A., Abendroth, J., King, D. and Swensen, T. (2011) Comparison of rowing on a Concept 2 stationary and dynamic ergometer. *Journal of Sports Science and Medicine,* 10, 267-273.

Bishop, D. (2000) Physiological predictors of flat-water kayak performance in women. *European Journal of Applied Physiology,* 82(1-2), 91-7.

Bishop, D., Bonetti, D. and Dawson, B. (2001) The effect of three different warm-up intensities on kayak ergometer performance. *Medicine and Science in Sports and Exercise,* 33(6), 1026-32.

Bishop, D., Bonetti, D. and Dawson, B. (2002) The influence of pacing strategy on VO_2 and supramaximal kayak performance. *Medicine and Science in Sports and Exercise,* 34(6), 1041-7.

Bishop, D., Bonetti, D. and Spencer, M. (2003) The effect of an intermittent, high-intensity warm-up on supramaximal kayak ergometer performance. *Journal of Sports Science,* 21(1), 13-20.

Brown, M.B., Lauder, M. and Dyson, R. (2010) Activation and contribution of trunk and leg musculature to force production during on-water sprint kayak performance. *28 International Conference on Biomechanics in Sports*. Marquette, Michigan, USA.

Campagna, P.D. (1986) A kayak ergometer for dry-land testing and conditioning. *IV International Symposium on Biomechanics in Sports.* Halifax, Canada.

Campagna, P.D., Brien, D., Holt, L.E., Alexander, A.B. and Greenberger, H. (1982) A biomechanical comparison of Olympic flatwater kayaking and a dry-land kayak ergometer. *Canadian Journal of Applied Sport Sciences,* 7, 242.

Campagna, P.D., Grandy, S.A., Gorelick, M. and Robinson, M. (1998) The relationship between power output and kayaking performance. *Medicine and Science in Sports and Exercise,* 30(5), 31.

Caplan, N. (2009) The influence of paddle orientation on boat velocity in canoeing. *International Journal of Sport Science and Engineering,* 3(3), 131-139.

Caplan, N. and Gardner, T. (2005) The influence of stretcher height on the mechanical effectiveness of rowing. *Journal of Applied Biomechanics,* (21)3, 286-296.

Caplan, N. and Gardner, T. (2008) The influence of a three week familiarisation period on rowing mechanics at a new stretcher position. *International Journal of Sport Science and Engineering,* 2(1), 15-22.

Caubet, J.M. (1999) Estudio comparativo de los parámetros cinemáticos de la técnica de paleo, en un ergómetro de piragüismo y en agua. *Apunts. Medicina de l´esport,* 34(131), 5-10.

Colloud, F., Bahuaud, P., Doriot, N., Champely, S. and Cheze, L. (2006) Fixed versus free-floating stretcher mechanism in rowing ergometers: Mechanical aspects. *Journal of Sports Sciences,* 24(5), 479-493.

Costill, D.L., Kovaleski, J., Porter, D., Fielding, R. and King, D. (1985) Energy expenditure during front crawl swimming: prediction in middle distance events. *International Journal of Sports Medicine,* 6(5), 266-270.

Craig, A.B. and Pendergast, D.R. (1979) Relationships of the stroke rate, distance per stroke, and velocity in competitive swimming. *Medicine and Science in Sports and Exercise*, 11(3), 278-283.

Craig, A.B., Skehan, P.L., Pawelczyk, J.A. and Boomer, W.L. (1985) Velocity, stroke rate, and distance per stroke during elite swimming competition. *Medicine and Science in Sports and Exercise,* 17(6), 625-634.

Cram, J. and Criswell, E. (2010) *Cram's Introduction to Surface Electromyography,* Ontario: Jones and Bartlett.

Cuesta, G., Polo, J.M. and Padilla, S. (1991) Correlación entre la marca deportiva obtenida en test de campo y parámetros fisiológicos obtenidos en laboratorio, en piragüistas adolescentes. *Apunts,* Medicina de l'esport, 18, 130-142.

Chan, S.C., Ferguson, S.J., Wuertz, K. and Gantenbein-Ritter, B. (2011) Biological response of the intervertebral disc to repetitive short-term cyclic torsion. *Spine,* 36(21), 2021-30.

East, D.J. (1970) An analysis of stroke frequency, stroke length and performance. *New Zealand Journal of Health, Physical Education and Recreation,* (3), 16-27.

Elliott, B., Lyttle, A. and Birkett, O. (2002) The RowPerfect ergometer: a training aid for on-water single scull rowing. *Sports Biomechanics,* 1(2), 123-34.

Elliott, E.H., Hamill, J. and Derrick, T.R. (1993) In-shoe pressure distribution during ergometer rowing in novice and experienced rowers. In: Hamill, J., Derrick, T. R. & Elliot, E. H. (Ed.) *Biomechanics of Sport XI: Proceeding of the XI Symposium of the International Symposium of Biomechanics in Sports.* Amherst, MA: International Society of Biomechanics in Sports.

Espinosa, M. (2011) Validación metodológica del análisis cinemático 3D del ciclo de palada en el piragüismo de velocidad. Estudio piloto. *Motricidad. European Journal of Human Movement.,* 26, 39-54.

Fleming, N., Donne, B., Fletcher, D. and Mahony, N. (2012) A biomechanical assessment of ergometer task specificity in elite flatwater kayakers. *Journal of Sports Science and Medicine,* 11(1), 16-25.

Fleming, N., Donne, B. and Mahony, N. (2007) Electromyographic and kinesiological analysis of the kayak stroke: comparison of on-water and on-ergometer data across exercise intensity. *Proceedings of the 12th Annual Congress of the European College of Sports Sciences.*

Fry, R.W. and Morton, A.R. (1991) Physiological and kinanthropometric attributes of elite flatwater kayakists. *Medicine and Science in Sports and Exercise,* 23(11), 1297-301.

Gowitzke, A. and Brown, B. (1986) Some qualitative comparisons of bent and straight canoe paddling techniques. *IV International Symposium on Biomechanics in Sports.* Halifax, Canada.

Hay, J. and Yanai, T. (1996) Evaluating the techniques of elite U.S. kayakers. *Unpublished report of U.S. Olympic Committee and U.S. canoe and kayak team.* University of Iowa, Iowa, USA.

Hay, J. (1985) The biomechanics of sports techniques, Englewood Cliffs, New York: Prentice Hall.

Ho, S.R., Smith, R. and O'Meara, D. (2009) Biomechanical analysis of dragon boat paddling: A comparison of elite and sub-elite paddlers. *Journal of Sports Sciences,* 27(1), 37-47.

Hofmijster, M., Landman, E., Smith, R. and Van Soest, A. (2007) Effect of stroke rate on the distribution of net mechanical power in rowing. *Journal of Sports Sciences,* 25(4), 403-411.

ICF (2011) Flatwater racing competition rules. Lausanne, International Canoe Federation.

Issurin, V. (1998) Analysis of the race strategy of world-class kayakers. In Issurin, V. (Ed.) *Science & practice of canoe/kayak high-performance training: selected articles in memory of junior world champion Nevo Eitan.* Tel-Aviv, Elite Sport Department of Israel, Israel.

Jackson, P.S. (1995) Performance prediction for Olympic kayaks. *Journal of Sports Sciences,* 13(3), 239-45.

Jackson, P.S., Locke, N. and Brown, P. (1992) The hydrodynamics of paddle propulsion. *Proceedings of the 11th Australasian Fluid Mechanics Conference,* Hobart, University of Tasmania, 14-18 Dec 1992.

Kendal, S.J. and Sanders, R.H. (1992) The technique of elite flatwater kayak paddlers using the wing paddle. *International Journal of Sport Biomechanics,* 8(3), 233-250.

Klentrou, P. and Montpetit, R. (1991) Effect of stroke rate and body mass on VO2 in crawl swimming. *Journal of Swimming Research,* 7(3), 26-30.

Kollmitzer, J. (1994) Error and practical test for 3-D gait analysis system setups with videometry and forceplates. *Third international symposium on 3-D analysis of human movement.* Stockholm, Sweden., 49-52.

Kranzl, A., Kollmitzer, J. and Zwick, E.B. (1996) 3-D kinematic analysis of the forward stroke of white-water paddlers using a paddle-ergometer. In Haake, S. (Ed.) *Engineering of Sport. 1st International Conference on the Engineering of Sport,* Sheffield, England, 02-04 Jul 1996. Rotterdam, Balkema.

Kumar, S., Narayan, Y.B. and Zedka, M.M. (1996) An electromyographic study of unresisted trunk rotation with normal velocity among healthy subjects. *Spine,* 21(13), 1500-1512.

Lamb, D.H. (1989) A kinematic comparison of ergometer and on-water rowing. *Am Journal of Sports Medicine,* 17(3), 367-73.

Larsson, B., Larsen, J., Modest, R., Serup, B. and Secher, N.H. (1988) A new kayak ergometer based on wing resistance. *Ergonomics,* 31(11), 1701-1707.

Logan, S.M. and Holt, L.E. (1985) The flatwater kayak stroke. *National Strength and Conditioning Association Journal,* 7(5), 4-11.

López-Plaza, D., Alacid, F., Vaquero-Cristóbal, R., López-Miñarro, P.Á. and Muyor, J.M. (2012) The influence of different stroke paces on kinematics during kayak-ergometer paddling. *IV International Congress of coaches on sprint canoeing.* Catoira, University of Vigo.

López, C. and Ribas, J. (2011) Quantitative analysis of kayak paddling technique: definition of an optimal stroke profile. *Revista Andaluza de Medicina del Deporte.,* 4(3), 91-95.

Mann, R.V. and Kearney, J.T. (1980) A biomechanical analysis of the Olympic-style flatwater kayak stroke. *Medicine and Science in Sports and Exercise,* 12(3), 183-188.

Marchetti, P.H., Kohn, A.F. and Duarte, D. (2011) Selective activation of the rectus abdominis muscle during low-intensity and fatiguing tasks. *Journal of Sports Science and Medicine,* 10, 322-327.

Marras, W.S., Davis, K.G. and Granata, K.P. (1998) Trunk muscle activities during asymmetric twisting motions. *Journal of Electromyography and Kinesiology,* 8(4), 247-256.

McGill, S.M. (1991) Electromyographic Activity of the Abdominal and Low-Back Musculature during the Generation of Isometric and Dynamic Axial Trunk Torque - Implications for Lumbar Mechanics. *Journal of Orthopaedic Research,* 9(1), 91-103.

McGregor, A.H., Bull, A.M. and Byng-Maddick, R. (2004) A comparison of rowing technique at different stroke rates: A description of sequencing, force production and kinematics. *International Journal of Sports Medicine,* 25(6), 465-470.

Michael, J.S., Rooney, K.B. and Smith, R. (2008) The metabolic demands of kayaking: a review. *Journal of Sport Science and Medicine,* 7(1), 1-7.

Michael, J.S., Rooney, K.B. and Smith, R. (2012) The dynamics of elite paddling on a kayak simulator. *Journal of Sports Sciences,* 1(8), 1-8.

Michael, J.S., Smith, R. and Rooney, K. (2010) Physiological Responses to Kayaking with a Swivel Seat. *International Journal of Sports Medicine,* 31(8), 555-560.

Michael, J.S., Smith, R. and Rooney, K. (2009) Determinants of kayak paddling performance. *Sports Biomechanics,* 8(2), 167-179.

Ong, K., Elliott, B. and Ackland, T. (2006) Performance Tolerance and Boat Set-up in Elite Sprint Kayaking. *Sports Biomechanics,* 5(1), 77-94.

Ong, K., Ackland, T. and Hume, P. (2005) Equipment Set-up among Olympic Sprint and Slalom Kayak Paddlers. *Sports Biomechanics,* 4(1), 47-58.

Paddling.net. (2010) Swivel seats in ICF K1's. [Online]. Available from: http://www.paddling.net/message/showThread.html?fid=advice&tid=1245293. (Accessed 14 February 2012).

Payton, C.J., Bartlett, R.M. (2008) *Biomechanical evaluation of movement is sport and exercise,* Oxon, Routledge.

Pendergast, D., Cerretelli, P. and Rennie, D. (1979) Aerobic and glycolytic metabolism in arm exercise. *Journal of Applied Physiology,* 47(4), 754-60.

Pendergast, D., Mollendorf, J., Zamparo, P., Termin, A., Bushnell, D. and Paschke, D. (2005) The influence of drag on human locomotion in water. *Undersea Hyperbaric Medicine,* 32(1), 45-57.

Perneger, T. (1998) What's wrong with Bonferroni adjustments. *BMJ,* 316, 1236-38.

Petrone, N., Isotti, A. and Guerrini, G. (2006) Biomechanical Analysis of Olympic Kayak Athletes During Indoor Paddling. *The Engineering of Sport 6.* Springer New York.

Petrone, N., Quaresimin, M. and Spina, S. (1998) A load acquisition device for the paddling action on olympic kayak. In: Allison (Ed.) *Experimental mechanics, advances in design, testing and analysis: proceedings of XI ICEM,.* Balkema, Rotterdam.

Pink, M., Perry, J., Browne, A., Scovazzo, M.L. and Kerrigan, J. (1991) The Normal Shoulder During Freestyle Swimming - an Electromyographic and Cinematographic Analysis of 12 Muscles. *American Journal of Sports Medicine*, 19(6), 569-576.

Plagenhoef, S. (1979) Biomechanical analysis of Olympic flatwater kayaking and canoeing. *Research Quarterly*, 50(3), 443-59.

Rath, D. and Baker, J. (1997) National Sprint Kayak Championships: Race analysis booklet. *Unpublished report to the Australian Canoe Federation Inc.* Australian Institute of Sport, ACT, Australia.

Robinson, M.G., Holt, L.E. and Pelham, T.W. (2002) The technology of sprint racing canoe and kayak hull and paddle designs. *International Sports Journal,* 6(2), 68-85.

Sánchez, J.L. and Magaz, S. (1993) *La Técnica. Piragüismo (I).* Madrid, COE.

Sanders, R.H. and Baker, J.D. (1998) Evolution of technique in flatwater kayaking. In: Issurin, V. (Ed.) *Science & practice of canoe/kayak high-performance training: selected articles in memory of junior world champion Nevo Eitan.* Tel-Aviv, Elite Sport Department of Israel.

Sanders, R.H. and Kendal, S.J. (1992) A description of Olympic flatwater kayak stroke technique. *Australian Journal of Science in Medicine in Sport,* 24(1), 25-30.

Sanderson, B. and Martindale, W. (1986) Towards optimizing rowing technique. *Medicine and Science in Sport and Exercise,* 18(4), 454-69.

Sealey, R.M., Ness, K.F. and Leicht, A.S. (2011) Effect of self-selected and induced slow and fast paddling on stroke kinematics during 1000 m outrigger canoeing ergometry. *Journal of Sports Science and Medicine,* 10(1), 52-58.

Shapiro, R. and Kearney, J.T. (1986) Methodologic considerations for quantitative evaluation of paddling. *IV International Symposium on Biomechanics in Sports.* Halifax, Canada.

Shephard, R.J. (1987) Science and medicine of canoeing and kayaking. *Sports Medicine*, 4(1), 19-33.

Sperlich, J. and Baker, J.D. (2002) Biomechanical testing in elite canoeing. In Gianikkelis, K. E. (Ed.) *Scientific Proceedings of the XXth International Symposium on Biomechanics in Sports.* Cáceres, Universidad de Extremadura.

Steer, R.R., McGregor, A.H. and Bull, A.M. (2006) A comparison of kinematics and performance measures of two rowing ergometers. *Journal of Sports Science and Medicine*, 5(1), 52-59.

Stothart, J.P., Reardon, F.D. and Thoden, J.S. (1986a) Paddling ergometer kinematics of elite kayakers. *IV International Symposium on Biomechanics in Sports.* Halifax, Canada.

Stothart, J.P., Reardon, F.D. and Thoden, J.S. (1986b) A system for the evaluation of on-water stroke force development during canoe and kayak events. *IV International Symposium on Biomechanics in Sports.* Halifax, Canada.

Sumner, D., Sprigings, E., Bugg, J. and Heseltine, J. (2003) Fluid forces on kayak paddle blades of different design. *Sports Engineering,* 6(1), 11-19.

Telford, R.D. (1982) Specific performance analysis with air-braked ergometers. Part II: short duration work and power. *Journal of Sports Medicine and Physical Fitness,* 22(3), 349-357.

Tesch, P., Piehl, K., Wilson, G. and Karlsson, J. (1976) Physiological investigations of Swedish elite canoe competitors. *Medicine and Science in Sports,* 8(4), 214-218.

Tesch, P. (1983) Physiological characteristics of elite kayak paddlers. *Canadian Journal of Applied Sport Sciences,* 8(2), 87-91.

Toro, A. (1986) *Canoeing: an olympic sport,* San Francisco, Olympian Graphics.

Trevithick, B.A., Ginn, K.A., Halaki, M. and Balnave, R. (2007) Shoulder muscle recruitment patterns during a kayak stroke performed on a paddling ergometer. *Journal of Electromyography and Kinesiology,* 17(1), 74-79.

Urquhart, D.M. and Hodges, P.W. (2005) Differential activity of regions of transversus abdominis during trunk rotation. *European Spine Journal*, 14(4), 393-400.

van Deursen, D.L., Snijders, C.J., van Dieën, J.H., Kingma, I. and van Deursen, L.L. (2001) The effect of passive vertebral rotation on pressure in the nucleus pulposus. *Journal of Biomechanics*, 34(3), 405-08.

van Someren, K.A. and Dumbar, G.M.J. (1997) Supramaximal testing on a kayak ergometer: reliability and physiological responses. *Journal of Sports Science,* 15, 33-34.

van Someren, K.A. and Oliver, J.E. (2002) The efficacy of ergometry determined heart rates for flatwater kayak training. *International Journal of Sports Medicine,*, 23(1), 28-32.

van Someren, K.A., Phillips, G.R. and Palmer, G.S. (2000) Comparison of physiological responses to open water kayaking and kayak ergometry. *International Journal of Sports Medicine,* 21(3), 200-4.

van Someren, K.A., Phillips, G.R. and Sharp, N.C. (1999) Physiological responses to 200-m sprint kayak racing. *Journal of Sports Science,* 17(1), 46-47.

Veres, S., Robertson, P. and Broom, N. (2010) The influence of torsion on disc herniation when combined with flexion. *European Spine Journal,* 19(9), 1468-78.

Wagner, J., Bartmus, U. and de Marées, H. (1993) Three-axes gyro system quantifying the specific balance of rowing. *International Journal of Sports Medicine*, 14(Suppl 1), S35-S38.

Wassinger, C.A., Myers, J.B., Sell, T.C., Oyama, S., Rubenstein, E.N. and Lephart, S.M. (2011) Scapulohumeral kinematic assessment of the forward kayak stroke in experienced whitewater kayakers. *Sports Biomechanics,* 10(2), 98-109.

Witkowski, M., Wychowanski, M. and Buczek, M. (1989) Kayak ergometer EK2. *Biology and Sport,* 6(Suppl. 3), 307-308.

8. Appendices

Appendix 1. Participant Information Sheet

Appendix 2. Consent Form

Appendix 3. Pre-Physical Activity Questionnaire (PAR-Q)

Participant Information Sheet

Study Title: The effect of the choice of seat type on forward kayak paddling.

You are invited to take part in the above research project. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if anything is unclear or if you would like more information.

What is the purpose of the study?
The study will investigate how the choice of seat used influences kayak ergometer performance. The trunk rotator muscles activation and the stroke and kinematic parameters will be investigated for a fixed seat and a swivel seat.

What would be involved for me?
At the start of the session 10 electromyography (EMG) electrodes will be attached to your body using adhesive tape. These electrodes passively record muscle activity. Approximately twenty spherical reflective markers will also be attached, to allow your motion to be tracked.

Afterwards you will be asked to complete two 30-second forward paddling tests on a kayak ergometer at maximum intensity, one with a fixed seat and one with the swivel seat. Each test will be preceded by a period of relatively gentle paddling during which you will be able to get familiarising with the seat and the ergometer and then a warm-up. There will be a rest period of approximately 15 minutes between the two tests. During the paddling tests, your muscle activity and body movements will be recorded.

The session should last approximately 50-60 minutes.

Where will the research take place?
All testing will occur in the Biomechanics Lab at the University of Lincoln’s Human Performance Centre.

Why have I been invited?
As an elite kayaker you will be familiar with the use of the kayak ergometer, and will be able to perform a maximum test in a consistent way.

Do I have to take part?
Your participation in this study is entirely voluntary. If you do decide to participate, you have the right to withdraw from the study at any point and to request that your data not be used.

What do I need to do if I wish to take part?
Please read this Information Sheet and ask any questions that you may have relating to the proposed study. If you still wish to proceed then please read and sign the Consent Form, and return it to the investigator. The latter will ask you to complete a physical activity readiness questionnaire before confirming your participation.

Will my taking part in the study be kept confidential?
Your name will not be revealed in any report or publication, and no reference will be made which could link you to the study. All data collected will be handled in strict confidence, and will be seen only by the members of the research team.

What are the possible disadvantages and risks of participation?
There is a slight risk of injury associated with performing the test, similar to the risks encountered during a training session or a competition. These risks will be minimised by the warm-up and by a risk assessment carried out by the researcher prior to the testing session.

Some people may experience minor skin irritation resulting from the adhesive tape used to attach the reflective markers or electrodes, or from the alcohol wipes used to clean the electrode sites.

What are the possible benefits of taking part?
The findings of the study will provide further knowledge about the effects of swivel seat in terms of technique, performance and muscle force. Your personal results will be made available to you on request, as will the findings of the completed study. This information may help you to figure out how your kayaking performance would be when using a swivel seat in comparison with a fixed seat.

What if I have any concerns or queries?
For issues relating to the project, please contact either the researcher (Daniel López-Plaza, 10195409@students.ac.uk, 07596174996) or the project supervisor (Sandy Willmott, swillmott@lincoln.ac.uk, (01522) 886651).

If you would like to talk to someone about ethical issues relating to the project please contact Hannah Rigby (hrigby@lincoln.ac.uk, (01522) 837092) at the University of Lincoln.

Thank you for taking the time to read this information.

Daniel López-Plaza Palomo

Consent Form

Study Title: The effect of the choice of seat type on forward kayak paddling.

I agree to take part in this research project, and acknowledge that I understand the following statements:

- The full details of the research have been explained to me and I am fully aware of what is expected of me as a participant.
- I am responsible for providing information relating to my health status and/or previous experiences of unusual sensations/reactions caused by physical activity.
- I am not aware of any injury and/or illness that will affect my ability to perform the assessment.
- I am also responsible for reporting any unusual feelings or discomfort felt by myself during the assessment.
- I am aware that I am not obliged to complete the assessments and that I am able to stop at any point, for any reason.
- I am aware that my research results and any information I provide are fully confidential and will only be communicated to others if agreed so in advance.
- My participation in this study is completely voluntary. I understand that I may withdraw from the study at any time and may ask that any data concerning me that have been collected are destroyed.

I have read and understand the information above, and any questions that I had have been fully answered. I agree to participate in this study.

Name (Print):

Signature of Participant: Date:

If the participant is under the age of eighteen:

Name (Print): Date:

Signed (Parent/Guardian)

I declare that I have explained the testing procedure in full and have made myself available for any questions the participant may wish to ask.

Name (Print):

Signature of Researcher: Date:

Appendix 3. Physical Activity Readiness Questionnaire (PAR-Q)

Pre-Physical Activity/Laboratory Questionnaire

Name:______________________________

Date of Birth: ____/____/____

Age: ______

OFFICE USE ONLY		
Date checked:	____/____/____	
Screened by:		
Status: (circle)	Passed	Flag

The purpose of this questionnaire is to ensure that you are physically able to complete the exercise test(s) outlined to you in the Participant Information Sheet. Please answer the questions below honestly and completely. **All information provided is strictly confidential** and will only be viewed by the appropriate departmental staff member. Your co-operation is greatly appreciated.

*Please **CIRCLE** the most appropriate option/s and use **BLOCK CAPITALS** when providing further detail.

1. How would you describe your present level of activity?

Sedentary moderately active active highly active*

2. How would you describe your present level of fitness?

Very unfit moderately fit trained highly trained*

3. Have you had to consult your doctor within the last 6 months? Y/N*

If YES, please give brief details and alert the test/activity supervisor ______________________________

4. Are you presently taking any form of medication? Y/N*

If YES, please give brief details and alert the test/activity supervisor ______________________________

5. Do you suffer, or have you ever suffered from, any of the following:

Asthma? Y/N* Diabetes? Y/N* Bronchitis? Y/N*

Epilepsy? Y/N* High blood pressure? Y/N*

6. Do you suffer, or have you ever suffered from, any form of heart complaint? Y/N*

7. Is there history of heart disease in your family? Y/N*

8. Do you currently have any form of muscle or joint injury? Y/N*

9. Have you had any cause to suspend your normal training/activity during the past two weeks? Y/N*

10. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you? Y/N*

Declaration

I have completed this questionnaire honestly and completely and all questions were answered to my complete satisfaction. I undertake to ensure that any change to my ability to participate in physical activity safely is communicated to immediately to an appropriate Department of Sport, Coaching and Exercise Science staff member.

Signature of Subject: ______________________________Date: _________

I declare that I have reviewed this form in its entirety and have made myself available for any questions the student may wish to ask.

Signature of Researcher: ___________________________Date: _________